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REFLECTION CHARACTERISTICS OF ROAD SURFACES.

BY

PARRY MOON AND R. M. HUNT,

Massachusetts Institute of Technology.

The lighting of streets has always been on an empirical rather than a scientific basis. With city streets, where speeds are low and the seeing problem is not difficult, the present qualitative methods are satisfactory and will probably continue to be so. The lighting of interurban highways, however, is quite a different problem. The high speeds and dense traffic make the driver's visual task a peculiarly difficult one, while the area to be lighted is so large that the utmost economy in the utilization of light becomes imperative. There is a growing realization that the highway-lighting problem requires a scientific approach for its satisfactory solution.

Yet, despite the large amount of excellent research of the past few years, the subject of highway lighting remains on a qualitative basis. It would seem that an adequate development would entail a threefold research program:

1. Determination of the distribution of pavement brightness caused by a single lamp. Data to be obtained for typical pavements and results to be expressed in the simplest form.

2. Determination of visual acuity of the average human

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eye. Visual acuity to be expressed as a function of brightness of background, contrast, and glare.

3. Development of engineering methods of utilizing (1) and (2) in the predetermination of seeing conditions for any proposed highway lighting system. Study of best positioning of lamps, best candlepower distribution of luminaires, best type of pavement surface, etc.

Such a program has been under way for several years at Massachusetts Institute of Technology. The present paper deals with (1) only. To avoid misunderstandings we may state that our aim is not to obtain results of the highest accuracy on a definite square meter of a definite pavement, nor is it to obtain the exact variation from point to point of an entire pavement, caused by variations in wear, polish, or composition. The purpose has been to get approximate average data, representative of the three types of pavement used most frequently in this country. It is believed that the results can be considered as a solution of step (1) and that they will be useful in the future development of step (3).

The present research is by no means the first dealing with pavement brightness. The pioneer investigations of P. S. Millar [1] laid the foundation for modern work. Peri [2] in 1928 and A. K. Taylor [3] in 1930 obtained data, though not for all points on the surface. J. M. Waldram [4] in England and M. Cohu [5] in France have made most noteworthy contributions. It appears, however, that none of the previously published data gives a satisfactory answer to (1).

BASIS OF MEASUREMENT.

It is well known that with the usual system of highway lighting, objects are seen generally in silhouette. Even with objects of high reflection factor and with black pavements, the brightness of the pavement surface is so much greater than that of the object that contrast between the object and its background is essentially 100 per cent. The eye tends to adapt itself to the brightness of the pavement. Thus in the predetermination of seeing conditions on highways that are lighted in the usual manner, the most important factor is the pavement brightness distribution rather than the brightness of the object.

Unfortunately, *the pavement brightness distribution bears no relation whatever to the distribution of pavement illumination.* In general, the illumination at a given point P on the road surface is the summation of contributions from a number of lamps. The light from each lamp strikes the surface at P in a different way, so that both altitude and azimuth are usually different for the rays from each source. Since for a given illumination, the brightness of the surface depends to a marked extent on both these angles, it is evident that each lamp must be considered separately. The total illumination at P tells nothing about the brightness at P. This fact has been stated frequently. Yet isolux curves are still plotted for pavements; and the feeling persists in the minds of many illuminating engineers that from such curves it is possible, or will be possible by some esoteric scheme, to obtain the brightness distribution. Nothing could be further from the truth.

The study of the reflection properties of a pavement resolves itself into the determination of the brightness distribution in the bright streak formed on the pavement by a single source. This distribution depends on the following factors:

1. Pavement
   - Type, materials, finish, wear, polish, dust or rain on surface, etc.
2. Source
   - Candlepower distribution
   - Mounting height
   - Distance from observer
3. Observer
   - Height of eyes above pavement.

Of pavement characteristics there exists an infinite variety. In an engineering investigation, it is best to confine attention to a few representative pavements, at least for the present. The only simplification that presents itself in (2) is the use of a source having a uniform intensity in the directions considered. Since the driver's eyes are in most cases at a fairly constant distance above the pavement, it is customary to keep (3) fixed. For a given pavement this leaves the two independent variables, mounting height of lamp and distance

between lamp and observer. For each condition, B is to be obtained as a function of two coordinates x and y.

Having obtained data on brightness for a single lamp of uniform candlepower, the engineer can calculate brightness for other conditions. Asymmetric candlepower distributions are easily taken care of. Also, the brightness distribution caused by any number of luminaires arranged in any manner is obtained by superposing the individual brightness patterns.

Several methods can be used in measuring the brightness distribution. Tests can be conducted in the laboratory on a small sample of the pavement which is illuminated and viewed from various angles, or actual pavements can be used:

Small sample	Visual measurements (Taylor [3]) Photoelectric measurements (Cohu [5])
Actual Pavements	Visual measurements (Millar,[1] Peri,[2] Waldram [4]) Photoelectric Photographic (Waldram,[4, 6] Bloch [7])

All these schemes have been employed except the photoelectric measurement of actual pavements, which appears to be impracticable unless a very intense source is used. The photographic method was adopted for the present research.

METHODS OF MEASUREMENT.

Results were obtained on three pavements which were chosen as representative examples of American practice. The rough bituminous pavement had a surface composed of bitumen-coated stones averaging approximately one cm in diameter. The concrete pavement was free from admixture of coloring material and had a light-colored diffusing surface. The smooth bituminous pavement had a smooth black coating, free from gravel. All pavements had been in use for several years and were well polished by traffic.

Instead of making measurements on a full-size set-up, we decided to use a reduced scale of 1 : 5. This made possible the obtaining of data for greater widths of pavement than would be possible otherwise, and simplified changes in the mounting height of the lamp.

A 500-watt PS-40 incandescent lamp was mounted base-up and was used as the light source in all tests. The voltage at the socket was maintained constant at 110.0 volts. A candle-power-distribution curve indicated a fairly uniform candle-power over the angles used in our tests, the average intensity over this region being 800 candles. The actual heights of the filament above the pavement surface were 91.4, 137.2, 182.8 cm. corresponding to 4.57, 6.86, and 9.14 meters (15, 22.5, and 30 ft.) full size. Results were obtained with horizontal displacements of the lamp from the axis of the camera lens of 0, 3.0, and 7.6 m., full-scale. Averaging of the results obtained with these displacements allowed us to reduce the effect of haphazard pavement irregularities. Distances between camera lens and lamp were 9.14, 30.48, and 60.96 m, corresponding to full-size distances of 45.7, 152.4, and 304.8 m. (150, 500, and 1000 ft.).

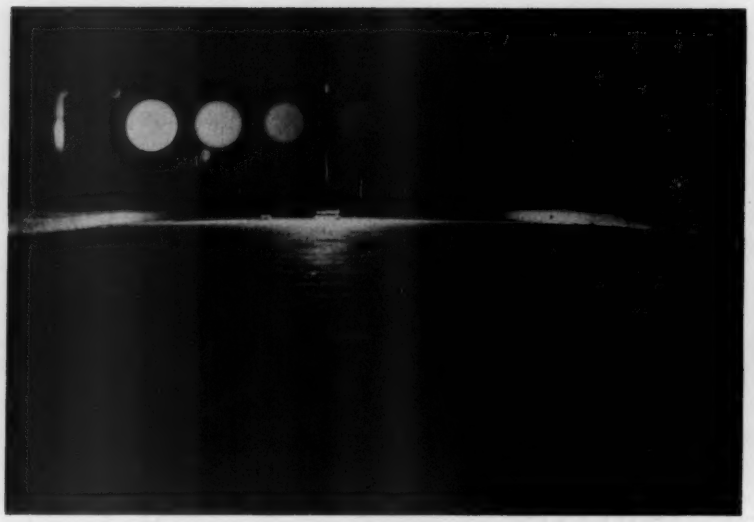
The axis of the lens was kept at a distance of 30.4 cm. above the pavement. This corresponds to a full-scale height of 152 cm. (5 ft.). The camera was focussed for an actual distance of 12.2 m. and was operated at $f/16$. Eastman Panatomic cut film was used and the exposure was 2 minutes.

A calibration box was included in each photograph of the pavements. The box was approximately 1 m. in length and had a series of opal-glass windows on one side. A 32-c.p., 6-volt lamp at one end of the box provided the light. The measured brightness of the openings with the lamp operating at 5.50 volts ranged from 0.050 to 15.1 candles per square meter. Figs. 1, 2, and 3 are typical photographs showing the calibration box, also the type of bright streaks obtained with the three pavements.

Tank development was used for the films, and a motor-driven agitator served to keep conditions uniform over the area of the film. Density measurements were made on the developed film by means of a photoelectric densitometer. Current from a Westinghouse Photox cell operated a sensitive galvanometer, the deflections of which were used in obtaining pavement brightnesses. Numerous horizontal traverses were made across the film at various distances below the horizon. The point on the pavement directly beneath the lamp was used as the center of coordinates, and displacements from

FIG. 1*a*.

FIG. 1*b*.



Rough Bituminous Pavement, showing bright streak caused by a single 500-watt lamp at a distance of (*a*) 304.8 m., (*b*) 152.4 m.

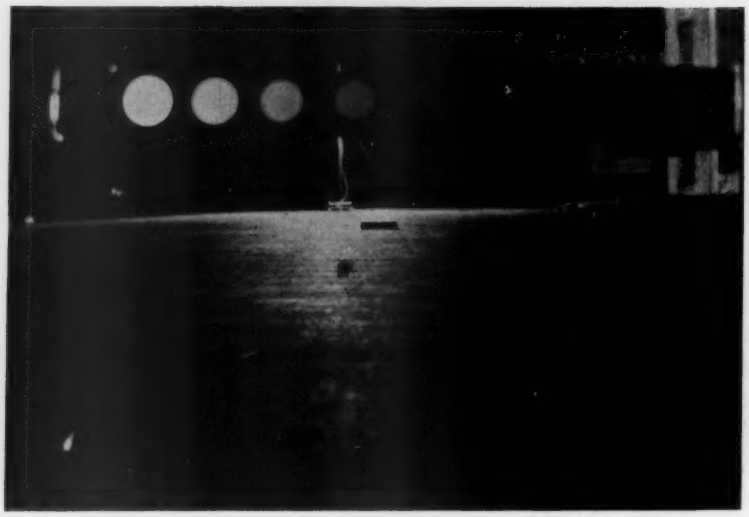
FIG. 2*a*.

FIG. 2*b*.

Concrete Pavement. Lamp at (*a*) 304.8 m., (*b*) 152.4 m.

FIG. 3*a*.

FIG. 3*b*.

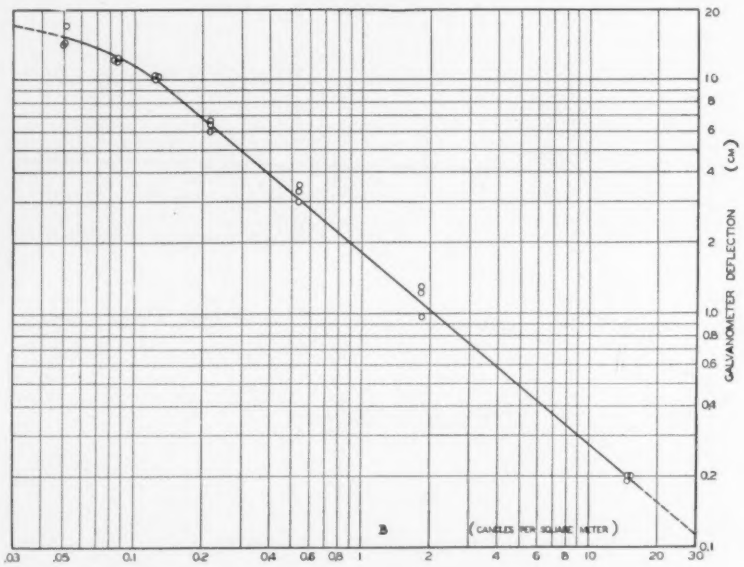


Smooth Bituminous Pavement. Lamp at (*a*) 304.8 m., (*b*) 152.4 m.

this position were read on the dials of the densitometer. A reading of 1 corresponded to a movement of 0.127 mm.

With each set of data, galvanometer deflections were obtained also for the spots corresponding to the windows of the calibration box. Since these spots were exposed and developed at the same time as the remainder of the film and since they were photometered under the same conditions, it is evident that variations in exposure, development, film speed,

FIG. 4.



Typical Calibration Curve for three negative films of lighted pavements.

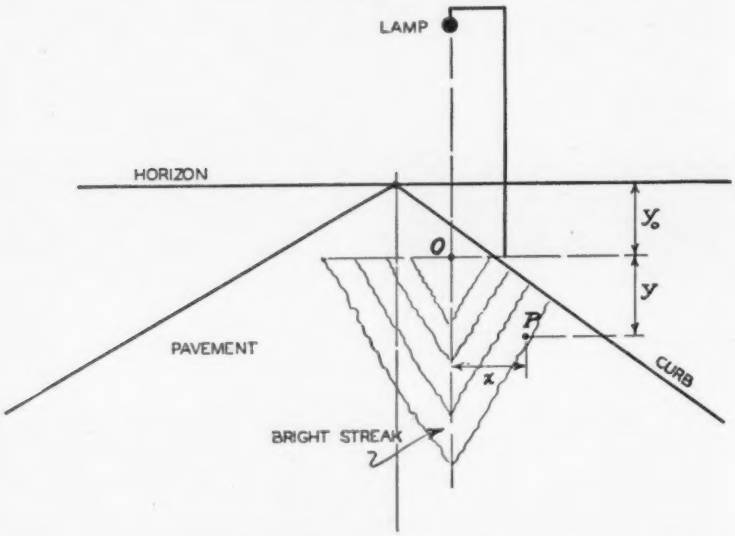
photocell output, or non-linearity of cell or galvanometer cause no errors in the results.

The next step was to translate galvanometer deflections into actual values of brightness of the pavement. For each film, a calibration curve was plotted, such as shown in Fig. 4, and from it were obtained the values of pavement brightness. When plotted on log-log paper, the calibration curves were straight lines over most of the range used in the tests.

CURVES.

Each photograph is, of course, a perspective view of the pavement from the viewpoint of the driver of a motor vehicle. Since we are always interested in the appearance of the road from this viewpoint alone, it is convenient to leave all measurements in terms of this perspective rather than to translate them into plan views which are meaningless as regards the visual problem. Fig. 5 shows the general arrangement.

FIG. 5.

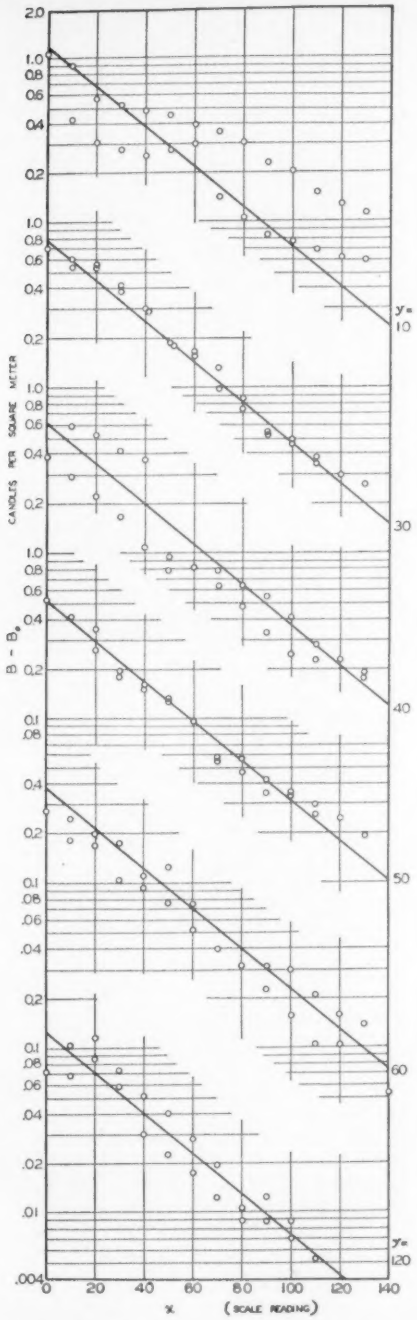


Perspective Drawing of a Road.

The point on the pavement directly beneath the lamp is denoted by O. P is an arbitrary point on the pavement where the brightness is desired. The coordinates of P are x and y, while y_0 is the fixed distance on the film from O to the horizon. All distances are measured in readings of the displacement dials of the densitometer.

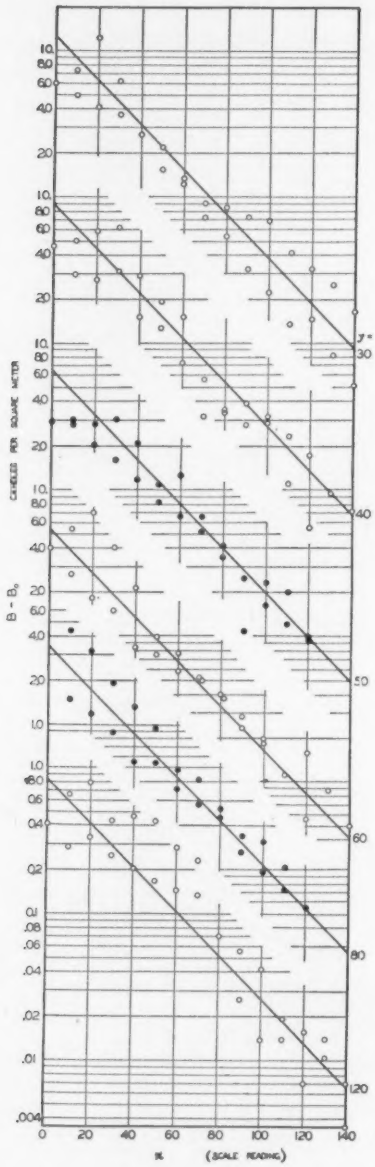
Figures 6 and 9 give the analysis of a typical film. It was found that if $\log (B - B_0)$ was plotted against x, the curve was approximately a straight line as shown in Fig. 6. Here B is the measured brightness and B_0 is a constant determined by trial. Also curves for various constant values of y are

FIG. 6.



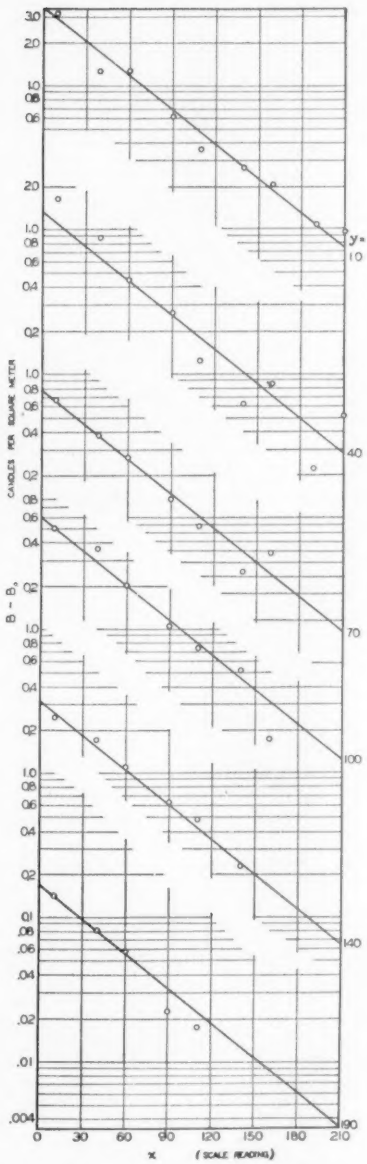
Family of Curves obtained from horizontal traverses on a single photograph of a rough bituminous pavement. Lamp at 152.4 m., $B_0 = 0.034$ c/m², $C' = 0.012$.

FIG. 7.



Curves Obtained from Horizontal Traverses. Concrete pavement, lamp at 152.4 m., $B_0 = 0.045$ c/m², $C' = 0.015$.

FIG. 8.



Curves Obtained from Horizontal Traverses. Smooth bituminous pavement, lamp at 152.4 m., $B_0 = 0.051$ c/m², $C' = 0.0081$.

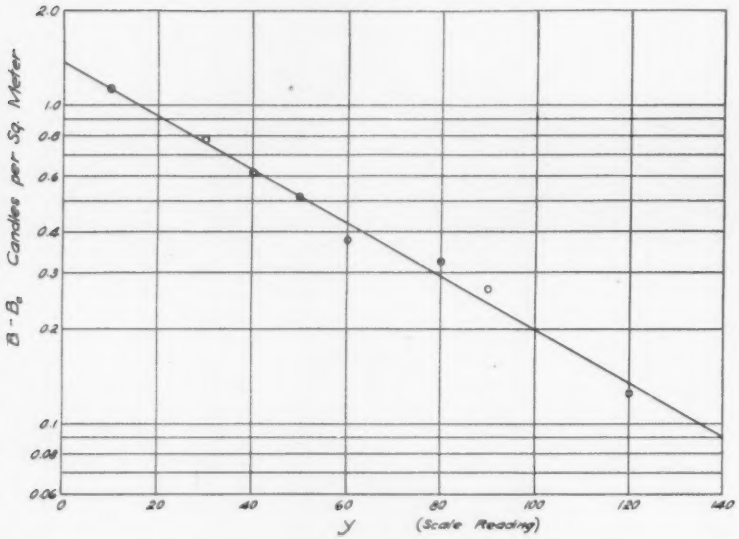
found to have the same slope. Thus all results can be expressed by the equation

$$B = A(10)^{-C'x-D'y} + B_0, \qquad (1)$$

where B = brightness of pavement at $P(c/m^2)$,

A, B_0 = constants (c/m^2),
C', D' = constants,
x, y = coordinates of P (dial readings).

FIG. 9.



Vertical Brightness Variation. Obtained from Fig. 6 by plotting values for $x = 0$. Rough bituminous pavement, lamp at 152.4 m., $A = 1.4$ c/m², $D' = 0.0085$.

For the rough bituminous pavement of Figs. 6 and 9, the values of the constants are

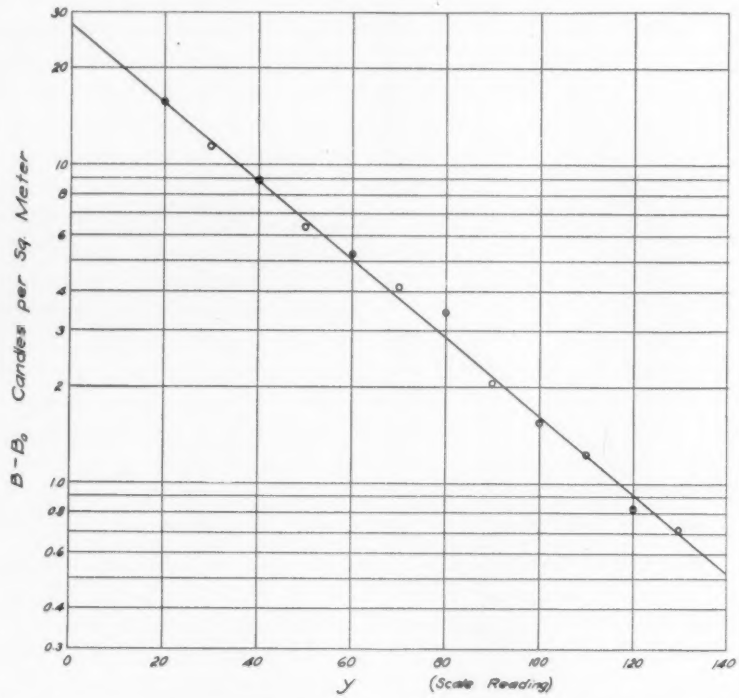
$$A = 1.37,$$
$$C' = 0.0123,$$
$$D' = 0.0085,$$
$$B_0 = 0.034.$$

Similar results for the concrete pavement are shown in Figs. 7 and 10. The slopes (and therefore the values of C'

and D') are not widely different from those for the rough bituminous pavement but the actual values of B are much higher for the concrete.

Figures 8 and 11 give the analysis of a typical film for the smooth bituminous pavement. Values of brightness are between those for the other two classes of pavements.

FIG. 10.



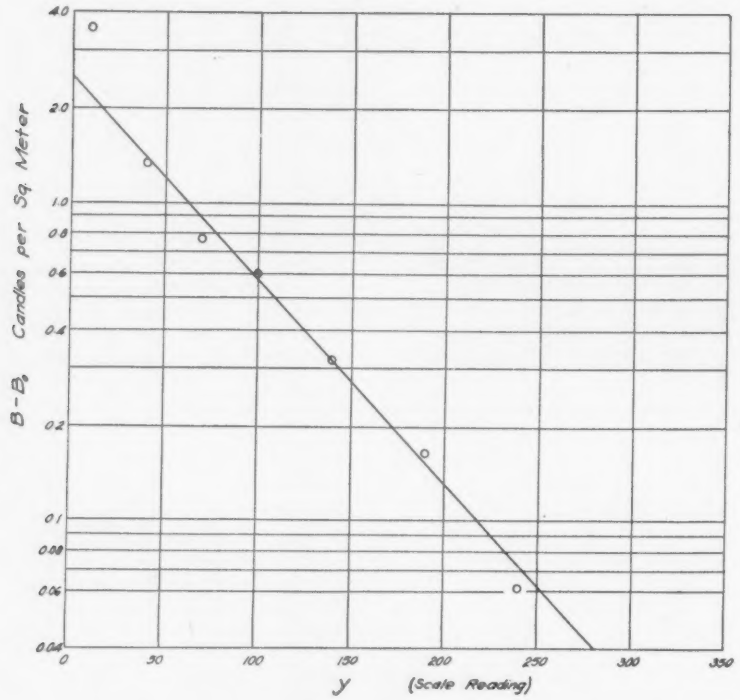
Vertical Brightness Variation. Obtained from Fig. 7 by plotting values for $x = 0$. Concrete pavement, lamp at 152.4 m., $A = 27.6$ c/m², $D' = 0.012$.

TABULATED RESULTS.

The analysis of one film gives a set of curves such as illustrated in Figs. 6 and 9. If desired, these curves can be replotted as a family of equal-brightness contours. In either case, the amount of information is so large that its visualization borders on the troublesome. If now the pages of curves are multiplied to take care of different pavement surfaces,

various mounting heights, distances, and displacements, a mental grasp of the interrelations becomes practically impossible. So after wasting considerable time in trying to determine relations among 30 or 40 curve sheets, we abandoned the attempt and developed the empirical formula of Eq. (1).

FIG. 11.



Vertical Brightness Variation. Obtained from Fig. 8 by plotting values for $x = 0$. Smooth bituminous pavement, lamp at 152.4 m., $A = 3.4$ c/m², $D' = 0.0066$.

It should be realized that we do not advance Eq. (1) as an exact representation of the brightness distribution. It is a purely empirical equation, chosen after numerous trials as the simplest form that will represent approximately the measured brightness distributions. The non-homogeneity of all actual pavement surfaces precludes the possibility of obtaining highly consistent data. Even if such exact data are obtained, say by employing a small homogeneous sample,

and even if the resulting data can be expressed by an exact equation, the increased value of the formula *as an engineering tool* is questionable because of the wide variations in pavements found in practice.

The other films were analyzed by plotting as in Figs. 6 and 9. The results are assembled in Table I. The fourth, fifth, and sixth columns give the experimentally determined values of A, C' and D' to be used in Eq. (1). A noteworthy result is that the mounting height of the lamp has no effect on the brightness distribution, though the illumination of the pavement beneath the lamp is changed by a ratio of 4 : 1. As would be expected, a lateral displacement of the lamp has no effect except the random one caused by variations in the properties of the pavement surface. It will be noted also that the maximum brightness A is essentially the same for the lamp at 152.4 m. and at 304.8 m.* The slopes C' and D', however, are almost exactly twice as great for 304.8 m. as for 152.4 m.

In other words, the bright streak on the pavement *keeps its form and brightness distribution* as the lamp is moved with respect to the observer, but the *scale* of the entire ensemble is altered according to the laws of perspective. These conclusions are seen to hold, within the limits of experimental error, for all three kinds of pavement.* Evidently this result effects a great simplification: for a given pavement only *one* brightness distribution is required to express all heights, all displacements, and all distances from 152 m. to infinity.

For a distance of 45.7 m. from lamp to observer, the foregoing conclusions are no longer true. Table I shows that the maximum brightness is greatly increased and the slopes are changed. However, for high-speed interurban traffic, lamps closer to the driver than 75 m. can have little or no effect on the brightness of the object background; and it seems likely that for the engineering treatment of highway lighting we are justified in considering the laws of perspective to be valid for pavement brightness distributions with lamps from 75 m. to ∞.

The new variables u and v are now introduced:

* For the concrete pavement, differences in polish cause wide variations in the results. These variations, however, do not justify any change in the general conclusions given above.

TABLE I.

Reflection Characteristics of Pavements.

Rough bituminous pavement, dry, $B_0 = 0.034$ c/m².

Distance (meters).	Mounting Height (meters).	Displacement (meters).	A (c/m²).	C'.	D'.	C.	D.
45.7	4.57	0	6.9	0.0030	0.0047	0.19	0.30
	4.57	3.0	6.9	0.0038	0.0047	0.24	0.30
	6.86	0	6.9	0.0031	0.0047	0.19	0.30
	6.86	3.0	6.9	0.0028	0.0047	0.18	0.30
	9.14	0	9.9	0.0027	0.0054	0.17	0.34
	9.14	3.0	12.7	0.0025	0.0041	0.16	0.26
152.4	Fig. 6	—	1.4	0.012	0.0085	0.23	0.16
	4.57	0	1.1	0.013	0.0084	0.25	0.16
	4.57	3.0	—	0.013	—	0.25	—
	6.86	0	1.3	0.011	0.0076	0.21	0.14
	6.86	3.0	1.4	0.014	0.0067	0.26	0.13
	6.86	7.6	1.1	0.013	0.0083	0.24	0.16
	9.14	0	1.4	0.014	0.0073	0.26	0.14
304.8	—	—	1.5	0.025	0.017	0.23	0.16
	4.57	0	1.3	0.032	0.016	0.30	0.15
	4.57	3.0	1.3	0.028	0.016	0.26	0.15
	6.86	0	1.4	0.030	0.018	0.29	0.17
	6.86	3.0	0.89	0.030	0.017	0.29	0.16
	9.14	0	1.6	0.025	0.015	0.24	0.14
	9.14	3.0	1.2	0.026	0.017	0.25	0.16
Concrete pavement, dry, $B_0 = 0.045$ c/m².							
152.4	Fig. 7	—	27.6	0.015	0.012	0.28	0.24
	4.57	0	3.4	0.016	0.015	0.30	0.28
	4.57	7.6	17.2	0.015	0.014	0.29	0.26
	6.86	0	11.6	0.014	0.016	0.27	0.30
	6.86	7.6	11.0	0.015	0.010	0.28	0.19
	9.14	0	11.6	0.014	0.013	0.27	0.25
	9.14	0	12.7	0.016	0.013	0.30	0.25
	9.14	7.6	10.6	0.015	0.013	0.29	0.25
304.8	4.57	0	6.9	0.031	0.020	0.30	0.19
	4.57	7.6	8.9	0.031	0.018	0.30	0.17
	6.86	0	4.8	0.029	0.017	0.27	0.16
	6.86	7.6	6.9	0.029	0.020	0.27	0.19
	9.14	7.6	6.0	0.028	0.017	0.26	0.16
Smooth bituminous pavement, dry, $B_0 = 0.051$ c/m².							
152.4	4.57	0	2.5	0.0080	0.0064	0.15	0.12
	6.86	0	2.5	0.0081	0.0064	0.15	0.12
	9.14	0	3.4	0.0081	0.0066	0.15	0.12
304.8	4.57	0	2.4	0.018	0.015	0.17	0.14
	6.86	0	2.8	0.020	0.015	0.19	0.14
	9.14	0	2.4	0.017	0.015	0.16	0.14

$$u = x/y_0, \qquad v = y/y_0,$$

where y_0 is 9.44 (dial reading) for 304.8 m. and 18.88 for 152.4 m. (Fig. 5). Eq. (1) now becomes

$$B = A(10)^{-Cu-Dv} + B_0, \tag{2}$$

where C and D are the new constants given in Table 1. These constants are seen to be independent of distance.*

Representative values of the three kinds of pavement were obtained by averaging and are given in Table II. Evidently

TABLE II.
Average Values of Coefficients.
Rough Bituminous Pavement.

Distance.	A (c/m²).	C.	D.	B_0.
152.4 m	1.25	0.245	0.147	0.034
304.8	1.32	0.264	0.155	0.034
Average	1.29	0.255	0.151	0.034
		Concrete Pavement.		
152.4	13.21	0.285	0.253	0.045
304.8	6.69	0.279	0.174	0.045
Average	9.95	0.282	0.213	0.045
		Smooth Bituminous Pavement.		
152.4	2.81	0.152	0.122	0.051
204.8	2.54	0.171	0.140	0.051
Average	2.67	0.161	0.131	0.051

the rough bituminous pavement appears much darker than either of the others. Its diffuse reflection factor is undoubtedly as high or higher than that for the smooth bituminous pavement, yet the smooth pavement has a maximum brightness more than twice that of the rough pavement. The concrete pavement exhibits great variations in brightness because of differences in polish, but the values are always several times as great as those for the bituminous pavements.

The values of C and D in Table II show that the three pavements give bright streaks of the same general shape and

* For the concrete pavement, differences in polish cause wide variations in the results. These variations, however, do not justify any change in the general conclusions given above.

proportions. This is also evidenced by Figs. 1, 2 and 3. The smooth bituminous pavement has the lowest values of slopes and therefore exhibits the greatest spread. The concrete shows the most concentrated bright streaks on the pavement.

CONCLUSIONS.

Brightness distributions have been obtained for three representative pavements with dry surfaces. A single incandescent lamp was used as source and was placed in various positions with respect to the observer. The difficulty of visualizing the resulting multiplicity of families of curves necessitated the development of an empirical formula for the brightness at any point on the pavement surface. A study of the experimentally determined coefficients in this equation led to the following conclusions:

1. The shape and brightness distribution in the bright pavement streak is independent of the distance of the lamp from the curb, except as influenced by non-homogeneity in the pavement surface.

2. Changing the mounting height of the lamp from 4.5 to 9 meters produces no discernible effect.

3. Altering the distance between observer and lamp changes the size of the streak according to the laws of perspective, but the brightness values and relative shape are unaltered. This conclusion applies to distances from observer to lamp of 150 meters or more, and probably holds to engineering accuracy at even smaller distances.

4. The three pavements, rated in order of increasing maximum brightness, are rough bituminous, smooth bituminous, concrete.

5. Rated in order of increasing spread of the bright streak, they are concrete, rough bituminous, smooth bituminous.

A word might be said about the use of the data. From Eq. (2) and the values of Table II one may plot lines of equal brightness produced by a single lamp of any intensity. For a perfectly symmetrical luminaire the result is a nest of similar triangles. For an asymmetric luminaire, the shapes are altered somewhat but can be obtained from Eq. (2) and the known isocandle diagram of the luminaire. Such distributions can be drawn on celluloid or other material, with one

complete diagram for each distance between the observer and the lamp. These diagrams are then placed on a perspective drawing of the road and can be moved about until the most uniform conditions are obtained. The actual brightness distribution with the resulting arrangement is obtained by superposition. Such a method of design has been used at Massachusetts Institute of Technology and will be described in another paper. We wish to express our thanks to Messrs. L. Cavendish and G. R. Jones for their help in this research.

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Burning of Coal and Coke Treated With Small Quantities of Chemicals.—MESSRS. NICHOLLS, RICE, LANDRY, and REID present a very comprehensive report on this subject in the U. S. Bureau of Mines Bulletin 404. Several investigations have been conducted in the past to determine what effect preheating fuels with chemicals dissolved or suspended in water had on the burning of fuels, the fuel bed, and on the ash. From the year 1934 to 1936 an investigation was conducted with the general object of measuring any effects of the chemicals by burning fuels under more closely controlled conditions than can be imposed in commercial equipment. Fuel beds of both the overfeed and underfeed type were studied and twenty-five different chemicals, not including their variations with or without water, were used. The tests of eastern coals treated with certain proprietary products ("fuel savers") showed that the treatments made no difference in the results within the range of duplication possible in tests of commercial boilers. The tests definitely disproved the claims of the vendors for large saving of fuel, elimination of smoke and soot deposits, reduction of clinkering, or any other change measurable in such tests. The results of the two-year investigation showed that one definite effect of treatments that could be beneficial in the burning of coals is that they may reduce the caking in the bed, for those coals that are not themselves strongly caking. This power to reduce caking amounts to small but definite effect, which, when subtracted from the normal ability of the coal to cake will make a large difference with a weakly caking coal, but no measurable change with a strongly caking coal. Sodium carbonate was, on the average, the most effective of the chemicals. Ratings were based on the results with 20 and 40 pounds of chemicals per ton.

R. H. O.

GROTTHUSS AND EINSTEIN.

BY

WILDER D. BANCROFT * AND RICHARD C. CLAPP.†

All photochemists realize now that Grotthuss in 1818 put forward the first law of photochemistry, that only those radiations which are absorbed by a substance can cause a chemical change in the system. This formulation includes bombardments by cathode rays, canal rays, radium emanations, etc., which were not known to Grotthuss.

There are a great many systems which absorb light without undergoing visible chemical change; but Grotthuss was able to increase the light-sensitiveness of certain reduction-oxidation systems by adding what he called a depolarizer and which was a reducing agent in his experiments. For instance, light cannot decompose an aqueous ferric chloride solution appreciably because the ferrous salt would react at once with the chlorine or hypochlorous acid thus formed. By taking ferric chloride in alcohol, the chlorine in the ferric chloride could react with the alcohol and thereby be removed from the sphere of action. Under these circumstances ferrous chloride was formed by the action of light.

This lead was followed up in the Cornell Laboratory. Bennett [1] showed that it is possible to add to a solution of copper sulphate a solution of white phosphorus in ether of such strength that there was no reduction in any reasonable time in the dark, whereas there was a reduction in the light. Metallic copper was not obtained because copper phosphide was formed in the presence of free phosphorus. Byk [2] had shown that a specially prepared Fehling's solution was not sensitive to red and orange light which is absorbed strongly by the solution; but is sensitive to the long ultra-violet. By adding a suitable amount of hydroquinone to Byk's solution,

* Visiting Professor on the Tallman Foundation, Bowdoin College.

† Senior in Bowdoin College.

[1] Bennett: *J. Phys. Chem.*, **16**, 782 (1912).

[2] Byk: *Z. physik. Chem.*, **49**, 659, 679 (1904).

Leighton [3] obtained a solution which did not decompose in the dark; but was reduced by red light. Whether the difference between the ultra-violet and red lights is solely a matter of the size of the quantum has not been proved by anybody.

The experiments by Grotthuss, Bennett, and Leighton have not been received with enthusiasm by photochemists. H. S. Taylor [4] says that "in stressing the analogy between photochemical and electrochemical processes Grotthuss and others have referred to the non-absorbing components of a photochemical system as depolarizers, and thus associated them with the electrochemical depolarizers which take part in electrode reactions on the discharge of ions. The quantum concept of photochemistry applied to such components sees in them merely reacting constituents of the system which may or may not partake in the reaction process depending on the energy quantities available."

On p. 518, H. S. Taylor says: "In the . . . dissociation of hydrogen iodide, the substance may be thought of as its own depolarizer." One has to shut one's eyes pretty tight not to see a difference between a system like hydrogen iodide, in which all the reacting constituents absorb the activating light, and a system like ferric chloride and alcohol, where the active light is not necessarily absorbed at all by the alcohol. Kistiakowsky [5] says that "the effect of 'cathodic depolarizers' is as easily explained on the basis of primary formation of excited molecules and their secondary reaction with reducing substances." This is merely saying in other words what Grotthuss said over a century ago. Kistiakowsky substitutes the term "active molecules" for "molecules tending to react." The only way that we know that they are "active molecules" is because they tend to react.

In 1912 the senior author [6] presented the formulation: "All radiations which are absorbed by a substance tend to eliminate that substance. It is entirely a question of chemistry whether any reaction takes place or what the reaction products are." In 1928 this was paraphrased by H.

[3] Leighton: *J. Phys. Chem.*, **17**, 205 (1913).

[4] Taylor: *J. Phys. Chem.*, **32**, 517 (1928).

[5] Kistiakowsky: "Photochemical Processes," 159 (1928).

[6] Bancroft: *Eighth Int. Congress Applied Chemistry*, **20**, 33 (1912).

S. Taylor [7] somewhat for the worse and, with one addition, was called the Second Law of Photochemistry. "The absorption of light is a quantum process involving one quantum per absorbed molecule (or atom). The photochemical yield is determined by the thermal reactions of the system produced by the light absorption.

"Of this second law the quantum concept of absorption is Einstein's contribution to the progress of photochemistry. The second half is a generalization from the experiments of numerous writers who, in testing Einstein's original ideas, have added enormously to the quantitative knowledge of mechanism in photochemical processes and demonstrated the factors which determine the yield from a given illuminated system."

It is interesting to note that sixteen years of experiments of numerous writers enabled Taylor to substitute the word "thermal" for "chemical" (a doubtful improvement) in a generalization made independently of Einstein's work.

It seems to us that Einstein's very important generalization that light is absorbed in quanta should form part of the third law of photochemistry and should be amplified somewhat. Since no univalent zinc sulphide is known as yet, it is difficult to see how, with our present chemical knowledge, we can account for the photochemical production of metallic zinc from lithopone or phosphorescing zinc sulphide without postulating that two light-quanta are taken up practically simultaneously by one atom of zinc.

In 1928 the senior author [8] wrote: "Fortunately for my peace of mind it does not come within the scope of this report to discuss the general accuracy of the Einstein equation; but it has been rather a surprise and grief to me to find so many people working hard over possible chain mechanisms before they are absolutely certain of the accuracy of their premises. Suppose we take a reaction which does not go in the light in the absence of a depolarizer and which goes in the dark in the presence of a sufficient concentration of the depolarizer. If we expose the system for a given length of time to a given intensity of light and vary the concentration

[7] Taylor: *J. Phys. Chem.*, **32**, 527 (1928).

[8] Bancroft: *J. Phys. Chem.*, **32**, 535 (1928).

of the depolarizer, what quantitative relations shall we find for the case that the absorption of effective light by the depolarizer is negligible? Shall we get one quantum per molecule as soon as a reaction occurs and will it stay constant until the reaction takes place or shall we get an increasing efficiency of light with increasing concentration of the depolarizer? I have never seen any account of such an experiment or any reference to such an experiment and yet such measurements should be made with a large number of reactions, because they are absolutely fundamental and because the results are independent of any assumption as to the mechanism of the photochemical reaction."

Matters have got worse rather than better during the last decade and it is now necessary to consider seriously just what Einstein did prove. We shall show that the gist of his discovery was that light is absorbed in quanta; and that there is no Law of Photo-Equivalence in the sense that the photochemist understands the term.

Glasstone [9] says: "Although the idea of photoequivalence was first put forward by Stark (1905) its influence in photochemistry was not felt until the law was proved thermodynamically by Einstein in 1912 and subsequently (1913) deduced by him on quite different theoretical grounds. According to this law each molecule taking part in a photochemical process absorbs one quantum of the radiation causing the reaction or, in other words each quantum absorbed brings about the decomposition of one molecule." This is not what the author was trying to say. If the absorption of one quantum necessarily involved the decomposition of one molecule, all colored substances would be decomposed by sunlight and we should live in a drab world, always in case we were able to live at all.[10]

Daniels, Mathews and Williams [11] do not commit themselves to any great extent. "According to Faraday's law each atom liberated at an electrode during electrolysis is accompanied by one electron (or two or three electrons,

[9] Glasstone: "Recent Advances in Physical Chemistry," 319 (1936).

[10] Cf. Plotnikow: *Z. wiss. Phot.*, **21**, 134 (1921).

[11] Daniels, Mathews and Williams: "Experimental Physical Chemistry," 274 (1929).

depending on the valence). It would seem not unreasonable that in photochemistry a similar situation exists and that the number of molecules reacting is equal to the number of quanta absorbed. This relation is known as Einstein's law of photochemical equivalence. Frequently the law does not seem to be valid; but it does express the facts in a sufficient number of cases to demand that it be given serious attention. Usually the failure of the law can be traced [ascribed?] to the complications of secondary reactions."

As we go back in time the statements become more definite. Kistiakowsky [12] says: "An exact formulation of the conditions necessary for the application of the quantum theory to chemical reactions is due to Einstein [13] whose first derivation of the so-called equivalence law is based solely on classical thermodynamics and Planck's radiation law. The derivation was given and is strictly valid only for a very special type of an ideal photochemical reaction: a completely reversible thermodynamic equilibrium between the black body radiation and a chemical system $AB \rightleftarrows A + B$; AB being decomposed on absorption of radiation of a characteristic frequency ν and this frequency being emitted in the reverse reaction $A + B \rightarrow AB$, which is assumed to be uninfluenced by radiation. Einstein showed that the introduction of radiation of the frequency ν, of a higher density (temperature) than that of the dark equilibrium, into this system, must result in a shift of equilibrium to the side of decomposition and that the decomposition of N molecules of AB requires the absorption of light-energy in amount equal to $Nh\nu$, where h is Planck's constant.

"In the next paper, Einstein [14] extended the derivation of the equivalence law to the case that a finite frequency-interval $d\nu$ is effective, other assumptions being unchanged. Later Einstein [15] took up the problem again, treating it from a different angle. In this the Bohr atom and light-absorption in discontinuous energy quanta were assumed as the basis of the whole calculation. The assumption was further made

[12] Kistiakowsky: "Photochemical Processes," **17**, 20 (1928).
[13] Einstein: *Ann. Physik*, (4), **37**, 332 (1912).
[14] Einstein: *Ann. Physik*, (4), **38**, 881 (1913).
[15] Einstein: *Ber. deutsch. physik. Ges.*, **18**, 315 (1916).

that, at a sufficiently low temperature, practically all the light-absorbing molecules of a photochemical system are in the lowest quantum state. From these assumptions, Einstein deduced that absorbed light energy in amount equal to $Nh\nu$ should bring to reaction N molecules, provided the time interval between the absorption of an energy quantum by a molecule and its subsequent reaction was small in comparison with the mean life of activated molecules, i.e., with time interval between absorption and re-emission of light-energy by a molecule."

"Warburg stressed the point that the suggested primary process can occur only if the quantum energy of the absorbed radiation is larger than the heat of dissociation of the molecules. Quantum energy being smaller, no dissociation will take place and activated molecules must be formed. These can react only on collisions and only in such a way that the (negative) heat of the resulting chemical change is smaller than the quantum energy of absorbed radiation. Warburg suggested that, in photochemical reactions of this last type, smaller quantum yields than theoretically calculated should be expected, since not all activated molecules will have the opportunity to react."

It will now be well to consider what we think that Einstein said and meant. In 1905—in a paper usually not cited—Einstein [16] said: "The undulatory theory of light, working with continuous space functions, has proved eminently satisfactory in dealing with the purely optical phenomena and will probably never be replaced by another theory. One must, however, remember that the optical phenomena correspond to averages in time and not to instantaneous values. In spite of the complete confirmation by experiment of the theory of bending, reflection, refraction, dispersion, etc., it is quite conceivable that the theory of light, working with continuous space-functions, may lead to experimental discrepancies if one applies it to the production and conversion of light.

"It seems to me, as a matter of fact, that the observations on 'black-body radiation,' photoluminescence, the production of cathode rays by ultra-violet light and other groups of

[16] Einstein: *Ann. Physik*, (4), **17**, 132 (1905).

phenomena dealing with production or conversion of light become more intelligible on the assumption that light-energy is distributed discontinuously in space. According to the assumption now suggested, the energy spreading from a luminous point is not distributed continuously in an ever-increasing volume but consists of a finite number of energy quanta localized in points in space, which move without breaking up and can be absorbed or produced only as units."

Einstein accounts for Stokes' Law of Fluorescence by postulating that monochromatic light of a definite energy-quantum is absorbed by a fluorescent-substance and is emitted, by some unspecified mechanism, as energy quanta of other sizes, which are therefore necessarily smaller than the originally-absorbed energy quantum. When there are exceptions to Stokes' Law, some other unspecified thing happens and that is that. All he is really doing is to show that the phenomena of fluorescence are not incompatible with the existence of light-quanta, provided one makes the assumptions necessary to eliminate whatever difficulties arise. Einstein would not claim any more than this for this part of the paper.

On p. 147 Einstein says: "We must assume that when a gas is ionized by ultra-violet light, one absorbed energy quantum is used for ionizing one gas molecule. From this it follows directly that the work of ionization (the work theoretically necessary to produce ionization) of a molecule cannot be greater than the energy of an absorbed effective energy quantum." If Kistiakowsky remembered reading this paragraph, one wonders why he credited the idea to Warburg.

On p. 148 Einstein says: "If each absorbed quantum of light-energy ionizes one molecule there must be between the absorbed light-quantity L and the number J of the gram-molecules ionized thereby the relation $J = \frac{L}{R\beta\nu}$. If our concept corresponds to reality, this relation must hold for each gas which (for the frequency in question) shows no appreciable absorption not connected with ionization."

That last sentence should have been italicized. It means that the equation holds whenever it does; but tells us nothing about when it will hold. Millikan was right in calling Einstein's $h\nu$ formula a mathematical hunch. It will also be

profitable to consider Einstein's second article.[17] "In the following paragraphs I shall deduce simultaneously the Wien radiation law and the photochemical equivalence law essentially by a thermodynamic process. By the equivalence law I mean the statement that for the decomposition of one gram-equivalent by a photochemical process there is needed an amount of radiation energy $Nh\nu$, where one denotes by N the number of molecules in a gram-mol., by h the well-known constant in Planck's radiation formula, and by ν the frequency of the effective radiation.[18] The law appears essentially as a consequence of the assumption that the number of the molecules decomposed per unit of time is proportional to the density of the effective radiation; one must emphasize, however, that the thermodynamic relations and the radiation law do not permit this assumption to be replaced by any other, as will be pointed out briefly at the end of the paper. From the following it appears clearly that the equivalence law, or the assumptions leading to it, holds only so long as the effective radiation falls within the range of Wien's law. For such radiation, however, there can scarcely be any question as to the validity of the law."

Einstein then discusses the effect of light on a gas which dissociates reversibly into two other gases according to the equation $m_1 = m_2 + m_3$. He makes two assumptions: that the molecules of m_1 decompose as though m_2 and m_3 were not present; and that the probability that a molecule of m_1 will decompose in a given unit of time is proportional to the monochromatic radiation density.

"It must be admitted that the correctness of the second assumption is not self-evident. This second assumption contains the statement that the chemical action of a radiation upon a substance is dependent on the total amount of the effective radiation and not on the intensity of radiation; the existence of a lower threshold of effectiveness for radiation is excluded completely by this assumption. We are in contradiction as to this with the results of two papers by E. Warburg,[19] through which I received the incentive for this paper."

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[17] Einstein: *Ann. Physik*, (4), **37**, 832 (1912).

[18] Cf. Einstein: *Ann. Physik*, (4), **17**, 132 (1905).

[19] Warburg: *Verh. deutsch. physik. Ges.*, **9**, 24 (1908); **9**, 21 (1909).

Einstein is probably right for the case he is discussing, where there is a reversible equilibrium. He is probably not right in cases in which there is an energy hump,[20] a concept of which Einstein never heard. He is certainly not right for the decomposition of fluorescent substances and he is probably not right for exothermal reactions in which there is no apparent equilibrium. These are special cases of the energy hump.

On p. 834 Einstein says: "From the two assumptions it follows that Z the number of molecules of m_1 decomposing per unit of time is given by the expression

$$Z = A\rho m_1.$$

From what has been said, the proportionality factor A can depend only the temperature of the gas T. From all this the equation holds also for the case in which the radiation density ρ (at the frequency ν_0) is different from that corresponding to the temperature of the gas."

The statement that A is a function of the temperature alone is true; but it is a misleading statement, because the nature of the reacting substances enters into it in a way that Einstein has apparently not taken into consideration. Because the chemical decomposition is proportional to the total light absorbed does not prove that the light-energy is converted quantitatively into chemical energy. It is only necessary that the percentage conversion at any given temperature shall be constant. The percentage conversion factor is concealed in proportionality factor A, though that has apparently never occurred to anybody before.

There is another way of looking at this matter which may be profitable. Fundamental facts cannot be established thermodynamically, and consequently one cannot deduce the equivalence of the light-quantum and the energy of dissociation thermodynamically. Not even Einstein can do that. From a given set of assumptions one may deduce new and interesting conclusions thermodynamically; but one must start from something, either guesses or observed facts. Einstein has done all that a mathematician can do. He has

[20] Bancroft and Magoffin: *J. Franklin Inst.*, **224**, 283, 475 (1937).

shown what postulates are necessary in order to deduce the law of photo-equivalence. When discussing the ionization of gases by ultra-violet light, he specified that there should be no appreciable absorption not accompanied by ionization. In other words the conversion factor for light-energy will be one hundred per cent. when and only when no absorbed light-energy is used for anything else. Einstein's law is like Thomson's law for voltaic cells. The heat energy is an exact measure of the electric energy in case the only heat evolved in the cell is Joule's heat.

Since the concept of a conversion factor is apparently an unfamiliar one to photochemists, it will be well to discuss it. In some cases the conversion is approximately one hundred per cent. and may be that exactly.[21] The heat of dissociation of molecular hydrogen is approximately 100,000 g. cals. per gram molecule. The mercury line, 2536 Å, has a quantum value of 112,000 g. cals. per gram molecule and causes the dissociation of molecular hydrogen. The cadmium line, 3262 Å, has a quantum value of 88,000 g. cals. per gram molecule and does not dissociate molecular hydrogen. The conversion factor is evidently not less than 90 per cent. and may be more. Norrish, Crone, and Saltmarsh [22] studied the photochemical decomposition of ketones and state that the quantum value of 3000 Å, the point in the spectrum at which decomposition begins, is 94,500 g. cals. which "is approximately equal to the energy of the carbon-carbon link." This is satisfactory as showing the importance of the magnitude of the quantum in this case. It does not necessarily mean one-hundred per cent. conversion. Norrish only claims forty per cent. quantum efficiency and other people consider that value too high.

H. S. Taylor [23] gives quantum values for the colors of the spectrum and we have added a column giving the values as volt-equivalents on the basis of 23,064 g. cals. per volt-equivalent:

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[21] Glasstone: "Recent Advances in Physical Chemistry," 326 (1936).

[22] Norrish, Crone and Saltmarsh: *J. Chem. Soc.*, **1934**, 1456.

[23] Taylor: "Elementary Physical Chemistry," 479 (1927); Mayer: *Z. angew. Chem.* **39**, 307 (1926).

TABLE I.

	$U = Nh\nu$ in calories	Volt-equivalents
Infra-red	<37,800	<1.6
Red	37,800–43,630	ca. 1.6–1.9
Orange	43,630–48,060	ca. 1.9–<2.1
Yellow	48,060–49,320	ca. <2.1–>2.1
Green	49,320–57,880	ca. >2.1–2.5
Blue	57,880–62,330	ca. 2.5–2.7
Violet	62,330–71,800	ca. 2.7–3.1
Ultra-violet	142,000 (ca. 2000 Å)	6.1+

If the conversion factor were 100 per cent. a copper sulphate solution should be reduced to metallic copper, which is not the case. Practically all colored solutions of electrolytes should be decomposed by the visible spectrum, which is not the case.[24] If we postulate 0.15 volt as a fairly good photochemical electromotive force, the conversion factor for the visible spectrum cannot exceed a few per cent. We shall see that solvated ions may be a disturbing factor.

According to Kistiakowsky,[25] "the action of light on certain dyes in the solid state, mainly in solid solutions [?] in thin collodion films, was the object of extensive and repeated studies by Lasareff and his co-workers. Simple relations indicated by their earlier investigations have subsequently proved more complicated than originally assumed; but, nevertheless, these investigations retain the historical importance of being the first photochemical experiments in which the study of the influence of wave-length of incident radiation on the rate of photochemical reaction was combined with exact measurements on absolute amounts of absorbed light-energy. Originally, Lasareff proposed that the rate of bleaching of different dyes in collodion films is determined solely by the amount of absorbed light-energy and is independent of the wave-length of incident radiation. The spectral region studied was between the limits 5400–6400 Å, and was thus rather narrow. The measurements of the absorbed light-energy revealed that the amounts of energy required for the decomposition of different dyes exceeded by far even their heats of combustion. In Table II are given the

[24] Cf. Plotnikow: *Z. wiss. Phot.*, **21**, 134 (1921).

[25] Kistiakowsky: "Photochemical Processes," 214 (1928).

TABLE II.

Quinaldine cyanine....	16,000 cal./gram [not gram-molecule]
Pinachrome.....	30,000 cal./gram [not gram-molecule]
Cyanine.....	48,000 cal./gram [not gram-molecule]
Lepidin cyanine.....	58,000 cal./gram [not gram-molecule]
Pinaverdol.....	117,000 cal./gram [not gram-molecule]

number of calories of radiant energy which cause the decomposition of one gram of corresponding dye. These values indicate, as Bodenstein pointed out, that hundreds of light quanta must be absorbed in order to decompose one dye molecule." Evidently, the conversion factor is very small for these cases.

Ackerman [26] showed that the fastness of a dye to light can be changed by adsorption on a fiber or a mordant. With equal weights of a given dye adsorbed on two different colorless fibers or mordants, the dye which is adsorbed the most strongly (farthest from adsorption saturation) will be the fastest to light provided there are no disturbing factors. The alizarine lakes illustrate one form of disturbing factor. The alumina lake is red, the tin lake is orange, and the zinc lake is lavender. While we do not yet know that this difference in color is sufficient to account for the observed differences in behavior to light, we can at least see that the three lakes are not strictly comparable.

Indigo is adsorbed more strongly by wool than by cotton, and indigo is faster to light on wool than on cotton. With approximately equal weights of indigo on the two fibers, the cotton sample faded completely in 198 hours of exposure in the Fade-ometer, while the wool sample was about three-fourths faded in 250 hours.

With Acid Green the alumina lake faded completely in nine hours, the zinc lake in seven hours and the tin lake in four hours. Special experiments showed that the order of decreasing adsorption is alumina, zinc and tin. Since a basic mordant adsorbs much less strongly after it has aged, the dyed mordant should then be less fast to light. Ackerman found this to be true. Acid Green was precipitated on alumina that had been aged for a month and on freshly precipitated stannic oxide. The Acid Green was adsorbed

[1] Ackerman: *J. Phys. Chem.*, **36**, 780 (1932).

more strongly on the tin oxide than on the alumina. For equal amounts of dye taken up, the tin oxide lake was faster to light than the alumina lake, reversing what happened with both mordants freshly precipitated.

These facts were, of course, not known to Einstein. They are a necessary consequence of the Grotthuss point of view and were predicted from it.

While a lake pigment is ordinarily faster to light than the same weight of dye in mass, this is not always the case. Lithopone was zinc sulphide absorbed on barium sulphate. The early lithopones blackened readily in the light with a setting-free of metallic zinc, while zinc sulphide will not blacken under the same conditions of exposure. The reason for this is that metallic zinc is adsorbed strongly by barium sulphate, thus making it possible for light to decompose zinc sulphide.[27] The photochemical decomposition of phosphorescent zinc sulphide is a similar phenomenon.[28]

If a colorless mordant acts as an oxidizing catalyst, the dye may be less fast to light on that mordant than when pure. It is claimed that zinc oxide may act in this way in ultra-violet light.[29] "Winther [30] studied the fluorescence of zinc oxide and some of its photosensitizing actions. For both processes, the near ultra-violet spectral region was found to be effective. Winther demonstrated that, in presence of illuminated zinc oxide, glycerine is oxidized to glycerose and that this process can be carried out either in presence of free oxygen or in presence of different inorganic compounds. In absence of air, lead carbonate is, for instance, reduced to metallic lead by the reducing action of glycerine."

From what has been said, it is clear that a photochemical reaction will take place if the conversion value of the light-quantum is greater than the decomposition energy of the system. If there is no transfer of energy from other molecules, no reaction can take place if the conversion energy of the light-quantum is less than the decomposition energy. To what extent is this the case? We have already quoted H. S.

[27] O'Brien: *J. Phys. Chem.*, **19**, 113 (1915).
[28] Job and Emschwiller: *Compt. rend.*, **177**, 313 (1923).
[29] Kistiakowsky: "Photochemical Processes," 185 (1928).
[30] Winther: *Z. wiss. Phot.*, **21**, 45, 141, 168, 175 (1921).

Taylor's version of the second law of photochemistry, the first sentence of which is that "absorption of light is a quantum process involving one quantum per absorbing molecule (or atom)."

We know that this is not necessarily true. If acetone is exposed to ultra-violet light, we get a decomposition to ethane and carbon monoxide, evidently due to the practically simultaneous absorption of two quanta by one molecule according to the equation:

$$CH_3COCH_3 + \text{light} \rightarrow 2\ CH_3 + CO \rightarrow C_2H_6 + CO.$$

If only one quantum had been absorbed per molecule the reaction products would have been ketene and methane, just as it is in pyrolysis:

$$CH_3COCH_3 + \text{heat} \rightarrow CH_3CO + CH_3 \rightarrow CH_2 : CO + CH_4.$$

Since the two carbon-carbon linkages are identical, it is perhaps not surprising that they break practically simultaneously. If one starts with methyl ethyl ketone, the two bonds, though somewhat different, must break practically simultaneously, because we get all three of the possible hydrocarbons,[31] ethane, propane, and butane. On the other hand Norrish, Crone and Saltmarsh [32] find that methyl butyl ketone breaks in the butyl group, giving propylene and acetone:

$$CH_3CH_2CH_2CH_2COCH_3 + \text{light} \rightarrow CH_3CH_2CH_2 + CH_2COCH_3 \rightarrow C_3H_6 + CH_3COCH_3.$$

Since the linkage between the two methylene groups can hardly have been the weakest one, there must have been a transfer of some at least of the energy absorbed at the methylene-carbonyl linkage. The methylene-methylene linkage could, therefore, have been broken even if the decomposition energy had been larger than one quantum. Since this was written Dr. Sheppard and his co-workers reported at the Rochester Meeting of the American Chemical Society that, in the presence of a suitable halogen-acceptor, erythrosine sensitizes silver bromide to light, absorbed by

[31] Norrish and Appleyard: *J. Chem. Soc.*, **1934**, 856.

[32] Norrish, Crone and Saltmarsh: *J. Chem. Soc.*, **1934**, 1456.

erythrosine without the erythrosine being decomposed. Apparently erythrosine goes into an activated state and then transfers energy to the silver bromide. This case was barred by Einstein.

Since benzene has three so-called double bonds, it could absorb three quanta simultaneously; nobody knows how many quanta a substance like rubber can absorb simultaneously; and there is no *a priori* reason why chorophyll should not absorb simultaneously the four quanta which the physicists postulate for the synthesis of formaldehyde. In other words, after twenty-five years intensive application of quantum theory to photochemistry, we cannot predict definitely whether a given photochemical reaction will or will not take place even though we know the values of the quantum and of the reaction energy. We can say that in one case the reaction probably will occur and that in another case it will probably not occur. Sometimes we shall be right and sometimes we shall be wrong.

It is time that we return to the Gods of the Copybook Maxims:

"With the Hopes that our World is built on they were utterly
out of touch.
They denied that the Moon was Stilton, they denied she was
even Dutch.
"They denied that Wishes were Horses; they denied that a
Pig had Wings.
So we worshipped the Gods of the Market Who promised
these beautiful Things."

A few experiments were made with the Byk-Leighton Fehling's solution. Solution *A* is 40 g. $CuSO_4 . 5\ H_2O$ in 200 cc. water; solution *B* is 200 g. sodium potassium tartrate in 400 cc. water; solution *C* is 20 g. NaOH in 200 cc. water; Fehling's solution is 2.5 cc. solution *A* + 15 cc. solution *B* + 10 cc. solution *C*. The hydroquinone solution is one gram of hydroquinone in 100 cc. water.

When 0.45 cc. of the hydroquinone solution is added to 27.5 cc. Fehling's solution, there is no reduction in the dark; but there is in the light behind a sodium dichromate or permanganate screen. This confirms Leighton's results.

The decomposition voltage of the Fehling's solution was found to be about 0.7 volt and of the Fehling's solution plus 0.45 cc. hydroquinone solution about 0.3 volt. The decomposition voltage of a molar solution of copper sulphate was about 1.5 volts, dropping to about 0.3 volt when saturated with hydroquinone. Possibly the anode over-voltage in the copper sulphate solution should be subtracted from the decomposition voltage; but that would make matters worse, so a discussion of that point is postponed to some indefinite, future time.

The Fehling's solution was reduced to cuprous oxide by the light from a Hanovia lamp, while the molar solution of copper sulphate was not. This seemed to fix the apparent voltage-equivalent of the ultra-violet light between 1.5 volts and 0.7 volt, instead of over three volts as given by the quantum value. When the ultra-violet light was turned on the copper sulphate and hydroquinone solution, there was no visible production of copper or cuprous oxide. There was a good deal of decomposition of the hydroquinone and it was possible that the carbonaceous material had absorbed the copper and masked it. When the copper sulphate solution was washed out of the carbonaceous matter as thoroughly as possible, no test for copper was obtained. Consequently, ultra-violet light cannot have an apparent voltage-equivalent greater than 0.2 volt for copper sulphate solution as compared with an apparent value of at least 0.8 volt for Fehling's solution.

A molar solution of copper sulphate had a potential drop of 1.3 volts impressed upon it by means of platinum electrodes and was then irradiated with a Hanovia lamp. No reduction to copper or cuprous oxide could be detected. Before deciding definitely that all the difficulty is in the conversion factor, a careful comparison of the spectra of the copper sulphate solution and of Fehling's solution should be made, and the two compared with the spectrum of the mercury vapor lamp. The facilities at our disposal did not permit of this; but there is no reason to suppose that this, when done, will introduce any special change.

In any event, the fact remains that copper sulphate solution and Fehling's solution apparently behave quite differently with reference to ultra-violet light, and that in

neither case is there any connection, obvious as yet, between the energy values of the light-quanta and the chemical decomposition produced by the ultra-violet light. It seems to us that this matter should have been stressed by the thermodynamical photochemists instead of apparently being ignored by them.

Since the color of copper ions varies with the degree of hydration,[33] there will be a photochemical action changing the degree of hydration without necessarily having much effect on the chemical potential of the copper ion. The larger the dehydration effect, the less energy will be available for a chemical decomposition corresponding to the electrolytic one. This is a point which must be kept in mind when dealing with solvated ions; and many of the metallic cations are solvated.

To determine whether solvation is the important item, anhydrous copper sulphate was exposed to ultra-violet light; but there was no perceptible reduction. Replacing the air by hydrogen and also adding zinc oxide to the anhydrous copper sulphate had no visible effect. When ultra-violet light acted on anhydrous copper sulphate, glycerine[34] and hydrogen, reduction to cuprous oxide took place.

This is apparently a case of the misleading experiment. Böhi[35] showed that in the presence of zinc oxide and glycerine or grape sugar, copper sulphate solution was reduced by ultra-violet light first to cuprous oxide and then to metallic copper, while no perceptible reduction was obtained in the absence of zinc oxide. Both these results have been confirmed by Mr. T. S. Chapman in the Cornell Laboratory. On this basis there must have been something introduced into the reacting vessel in the Bowdoin experiments which acted like zinc oxide. The catalytic agent was probably zinc oxide itself carried over from the rubber connections. Special experiments by Mr. Chapman in a similar apparatus showed that zinc oxide can be carried over in this way by a current of hydrogen, especially if any of the connections are new rubber.

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[33] Bancroft and Rogers: *J. Phys. Chem.*, **37**, 1061 (1933).

[34] Cf. Kistiakowsky: "Photochemical Processes," 185 (1928).

[35] Böhi: *Helv. Chim. Acta*, **12**, 121 (1929).

The question arose whether a polarized Fehling's solution would show an effective relation between decomposition voltage and photochemical action in the case of red light. The beaker containing the Fehling's solution and the electrodes were placed in a larger beaker containing a fairly dilute solution of potassium permanganate; two 100-watt lamps were placed outside the permanganate screen. The platinum electrodes in the inner beaker were placed as close to the side of the beaker as possible and were set at an angle so as to be exposed as efficiently as possible to the source of light. Since the minimum decomposition voltage had been found to be about 0.7 volt, the red light was first tried for twenty minutes with an impressed voltage on the solution of 0.6 volt. No deposit was obtained at the cathode. Under similar conditions an impressed voltage of 0.65 volt produced traces of a greenish filmy deposit. With somewhat higher voltages, practically the same sequence of increasing deposits was obtained both with and without the red illumination.

However, when an impressed voltage of 1.0 volt was used and the current was allowed to flow without red illumination (with screen of Fehling's solution) and with red illumination (with screen of permanganate), a definitely greater deposit was obtained with the red light. With the higher impressed voltages and consequently greater currents, there was more heating effect and consequently an increased conductance and more current. Special experiments showed that the bulk of the effect was due to heating and that the effect of light was apparently not more than 0.05 volt.

In a sense this has all been known for a long time; but it has been crowded out of the picture by the so-called Law of Photo-Equivalence. Everybody knows that the action of light on a voltaic cell does not produce a change in the electromotive force of the magnitude of the quantum involved. The values vary from a fraction of a millivolt to a fraction of a volt. With a colored solution like copper sulphate and a colored metal like copper, there is a possibility of a differential effect, as was realized by Leighton.[36] No such thing can occur with a silver electrode in a silver nitrate solution, using light in the visible spectrum. Wilderman[37] found one millivolt for

[36] Leighton: *J. Phys. Chem.*, **17**, 695 (1913).

[37] Wilderman: *Z. physik. Chem.*, **60**, 70 (1907).

this system. In experiments on other systems made with varying degrees of accuracy, Audubert [38] obtained 1–6 mv., Athanasiu [39] up to 4 mv., Schlivitch [40] up to 15 mv., Pélabon [41] not over 30 mv., Titlestad [42] about 70 mv. with uranous-uranyl sulphate, van Dyck [43] 100 mv. with cuprous oxide, Garrison [44] 200 mv. for cuprous oxide with more intense light. Winther [45] made what he called a light-accumulator, in which the reaction was $Fe^{\cdot\cdot} + Hg^{\cdot\cdot} + \text{Light} \rightarrow Fe^{\cdot\cdot\cdot} + Hg^{\cdot}$ and the maximum electromotive force was 140 mv. Winther [46] found 380 mv. for zinc oxide electrodes in presence of glycerine. There is nothing in any of this to justify any necessary relation between the size of the quantum absorbed and the electromotive force generated. All the evidence points to the conversion factor for light being very small in the case of the heavy-metal cations.

We have then to explain how ultra-violet light can reduce Fehling's solution or a mixture of copper sulphate, zinc oxide, and glycerine or glucose without apparently affecting the chemical potentials of the copper salts appreciably. The only possible answer is that we are dealing with a non-electrolytic reaction. Irradiated glycerine or glucose or decomposition products thereof reduce irradiated copper sulphate instead of irradiated copper sulphate oxidizing irradiated glycerine or glucose. We do not even know that there is any theoretical need of irradiating the copper sulphate, though it may be difficult to avoid this experimentally.

The general results of this paper are as follows:

1. The first law of photochemistry should read: Only those radiations which are absorbed by a substance can cause a chemical change in the system (Grotthuss, 1818). This formulation includes bombardments by cathode rays, canal rays, radium emanations, etc. which were not known to Grotthuss.

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[38] Audubert: *J. Chim. phys.*, **24**, 357 (1927).
[39] Athanasiu: *Compt. rend.*, **180**, 587 (1924).
[40] Schlivitch: *Compt. rend.*, **182**, 891 (1926).
[41] Pélabon: *Compt. rend.*, **151**, 641 (1910).
[42] Titlestad: *Z. physik. Chem.*, **72**, 257 (1910).
[43] van Dyck: *Z. physik. Chem.*, **127**, 249 (1927).
[44] Garrison: *J. Phys. Chem.*, **27**, 601 (1923).
[45] Winther: *Z. Elektrochemie*, **18**, 138 (1912).
[46] Winther: *Z. wiss. Phot.*, **21**, 167 (1922).

2. The second law of photochemistry should read: All radiations which are absorbed by a substance [and only those radiations] tend to eliminate that substance. It is entirely a question of chemistry whether any reaction takes place or what the reaction products are (Bancroft, 1912).

3. The third law of photochemistry should read: Light is absorbed discontinuously, by quanta, and not continuously (Einstein, 1905).

4. A corollary of the third law of photochemistry is that no reaction will take place if the reaction energy is larger than the absorbed quantum and that a reaction will take place if the absorbed quantum is larger than the reaction energy—provided there is no intramolecular or intermolecular transfer of energy, and provided that the conversion of light energy into chemical energy is quantitative.

5. The case of the ketones shows that there is intramolecular transfer of energy and the case of erythrosine shows that there is intermolecular transfer of energy. While the conversion factor for light-energy into chemical energy is approximately 100 per cent. (or unity) for molecular hydrogen, it is very small for some dyes and for photovoltaic cells. Consequently it is impossible to predict definitely whether a reaction will or will not take place even when one knows the reaction energy and the quantum value. No satisfactory statement of what determines the conversion factor or photochemical efficiency can be made.

6. It is probable that there is a relation between the type of spectrum and the high or low conversion factor for light energy; but no such relation appears to have been established as yet, perhaps because photochemists have not yet appreciated the importance of the conversion factor.

7. The decomposition-voltage of a molar solution of copper sulphate is about 1.5 volts, dropping to about 0.3 volt when sufficient hydroquinone is added. The decomposition-voltage of the Fehling's solution is about 0.7 volt, dropping to about 0.3 volt when hydroquinone is added in amount sufficient to cause the solution to be sensitive to red light. The conversion efficiency of the Fehling's solution both for ultra-violet and for red light is apparently of the order of twenty per cent. more or less. The conversion efficiency of ultra-violet light for a

copper sulphate solution is apparently less than can be determined by our present methods, probably less than five per cent.

8. Since the color of copper ions varies with the degree of hydration, the low energy efficiency with copper sulphate solutions may be due, at least in part, to a dehydrating action of the light. This would not apply to the anhydrous copper sulphate.

9. When glycerine is added to anhydrous copper sulphate and zinc oxide, ultra-violet light causes a reduction in the absence of oxygen.

10. The conversion factor of light for heavy-metal cations is very small. Consequently irradiated glycerine or glucose or some decomposition product reduces irradiated copper sulphate solution in the presence of zinc oxide, the reaction being non-electrolytic.

We thank Professor Kamerling for laboratory space, apparatus, supplies, and suggestions.

Bowdoin College,
June 19, 1937.

Turbine Locomotive Design Proposed.—(*Railway Age*, Vol. 103, No. 20.) A committee of the Railway Fuel and Traveling Engineer's Association recently reported a design for a locomotive to permit a practical and satisfactory application of a steam turbine and transmission to the driving wheels. The design is for a 4000 hp. condensing locomotive with direct mechanical drive, using 2–4–2–2–4–2 wheel arrangement and having a starting tractive force of 64,000 lb. Four cylindrical continuous tube, high-pressure and high-temperature boilers will be used; two located near each end of the locomotive cab. The steam pressure will be 1200 lb. and the steam temperature 850° F. The fuel will be low-grade furnace or distillate oil vaporized before it passes through the burner. A boiler efficiency of 85 per cent. should be obtained when pre-heated air is used. The main turbine for driving the locomotive is located in the center of the locomotive cab with shaft extending longitudinally; this turbine will be of the impulse-reaction type, designed for a speed of 8000 r.p.m. at 120 m.p.h. The bladed portion of the turbine consists of two 24 in. mean-diameter Curtis wheels in series, followed by 18 stages of reaction blading. Pinions will be used on both ends of the turbine shaft and are to mesh with gears to reduce the speed for drive shafts extending toward each truck. Each shaft at this point will connect directly through couplings to a combined hydraulic coupling and epicyclic gear with output shaft delivering power to a differential-type reversing gear having an output shaft extending over driving axles and with Hypoid pinions on this shaft to drive Hypoid gears on each driving axle. The main frame of the locomotive will be of cast steel in one piece. Only a small quantity of water need be carried for boiler feed since the exhaust steam will be discharged to a condenser and will be returned for re-use.

R. H. O.

MEASUREMENT OF LIGHT FROM A TELLURIUM VAPOR ARC.

BY

J. W. MARDEN, N. C. BEESE, AND GEORGE MEISTER.

As early as 1862 [1] it was known that the flame spectrum of tellurium vapor was of a continuous nature. It is because of the continuous spectrum of this element that investigations were carried out in adapting tellurium vapor into an artificial light source. A tellurium vapor lamp resembles, in external appearance, a low pressure quartz mercury arc lamp with liquid mercury pool electrodes. Because of the great chemical activity of highly heated tellurium vapor, pool type electrodes must be used. Even such refractory metals as tungsten, molybdenum and tantalum cannot be used as electrode material in these lamps. A design such as that described by R. Rompe [2] seems to work very satisfactorily (for experimental purposes). Figure 1 shows the lamp structure with metallic tellurium electrodes which melt at a temperature of 450° C. Tungsten wires making the external connections are completely immersed in the tellurium metal. The lamp is made of quartz to withstand the high operating temperatures. This particular structure is chosen to maintain an adequate and constant supply of liquid tellurium at each electrode during operation. A reservoir is added to the top of the lamp to enlarge the volume of added inert gas.

The purity of the tellurium should be the highest possible because of the deleterious effect of many impurities on the heated quartz walls. Small percentages of selenium are especially bad in this respect. Electrolytic tellurium of high purity was obtained from the Raritan Copper Co.[3]

OPERATING CONDITIONS.

These lamps must be operated on direct currents since they will not burn on the conventional 60-cycle supply lines.

[1] Simmler, *Pogg. Ann.*, **115**, 242, 425 (1862).

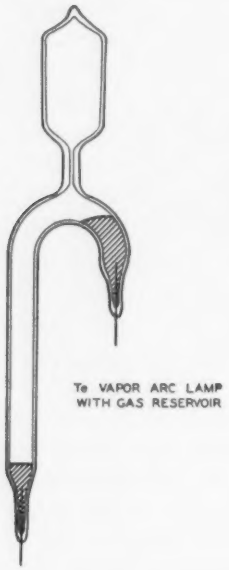
[2] Rompe, *Z. fur Phys.*, **101**, 214 (1936).

[3] Skowronski and Mosher, *Trans. Elec. Chem. Soc.*, **61**, 113 (1932.)

Rectified A.C. voltage from a full-wave rectifier with inductance in series with the lamp was used to operate most of the lamps. In this case sufficient inductance had to be added to prevent the minimum voltage falling below about 20 per cent. of the maximum peak voltage. Otherwise the lamp would extinguish itself.

The lower electrode is made anode and is maintained at such a temperature that the cathode pool is always full. Sometimes gold or platinum paint is required on the lower

FIG. 1.



electrode pool to maintain sufficient heat at the anode, since convection currents inside the lamp assist in heating the cathode.

An inverted U-shaped lamp was made and thermocouple junctions were attached to the lamp with asbestos ribbon about 1 cm above the electrode surfaces. During one observation the temperature near the cathode surface was 700° C., while that near the anode surface was 825° C. While the recorded temperatures are somewhat below actual values inside the lamp, the observed values show a difference in

temperature due to polarity and a vapor pressure of about 20 mm.[4] as indicated by 700° C.

The inert gases Ne, Ar and He were used for starting purposes. Tellurium seems to have the property of adsorbing or absorbing vast quantities of the inert gases. A lamp was made with a reservoir and side tube of about 3 cc. combined volume which were attached to the top of the lamp. In the side tube was mounted a section of a 10-watt 110 volt tungsten lamp filament so that it could be used as a pressure gauge. It was calibrated against a McLeod Gauge. The initial neon gas filling of 11 mm. was reduced to 7 mm. after the lamp had burned several hours. A similar lamp was made with a 20 cc. reservoir and a pressure gauge attached to the top of the lamp. This lamp was operated on the pumps for an hour with several different fillings of neon gas. This treatment saturated the tellurium with neon gas as well as flushed out volatile impurities. During the first fifty hours of burning, the gas pressure had not changed any observable amount.

Extreme purity of metal and gas filling is desirable, for small percentages of oxygen or hydrogen make the tellurium lamps inoperative. Small amounts of hydrogen are especially objectionable because of producing lamp blackening and increasing the starting voltages to excessive values.

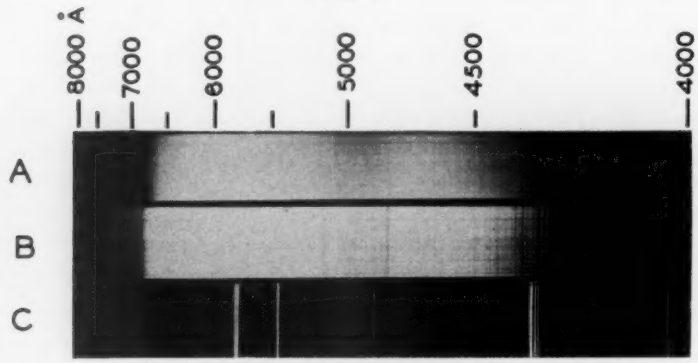
LIGHT OUTPUT.

The spectrum obtained from a tellurium vapor lamp is vastly different from the conventional "line spectra" obtained with most metallic vapor arc lamps. It consists of a banded structure throughout the visible region with a heavy continuous spectrum superimposed, giving an effect approximately that of an incandescent solid. In the ultraviolet region a line spectrum predominates with the strong resonance lines at 2386 and 2383 and 2142 Å. There is also a very weak continuous spectrum in the ultraviolet, the intensity of which decreases towards the shorter wave-lengths. The combination of an atomic continuous spectrum produced by the recombination of Te atoms with electrons and a banded molecular spectrum produces a very excellent artificial white light.

[4] Int. Crit. Tables.

At low temperatures, pressures and wattages the emitted light is a bluish white color, while at higher operating conditions the light becomes a yellowish white. At extremely high operating temperatures the light is a golden yellow color. This shifting of the color towards the red end of the spectrum with increasing temperatures is exactly opposite to that encountered in an incandescent solid whose spectral shift is described by Wiens Displacement law. While the initial bluish white light is obtained with a tellurium vapor pressure of only a few thousandths of a mm. mercury pressure,

FIG. 2.



A– TELLURIUM VAPOR ARC SPECTRUM
B– SOLAR SPECTRUM
C– MERCURY ARC SPECTRUM

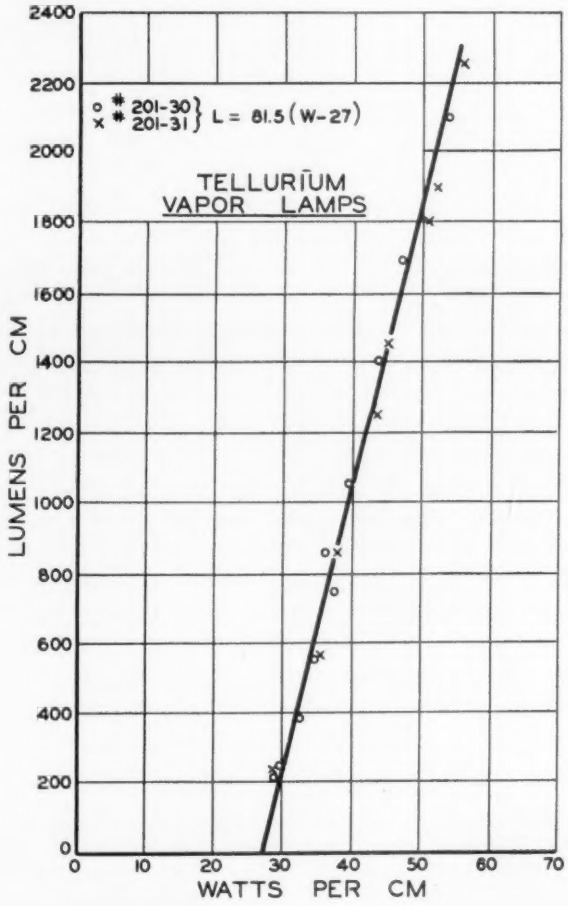
the golden yellow color is obtained with a vapor pressure above atmospheric pressure.

Figure 2 shows the tellurium spectrum in the visible region. A solar comparison spectrum and one from a mercury arc lamp is added. An analysis of the ultraviolet spectrum * revealed the presence of several impurities, the most important being lead, copper, iron, silicon and magnesium. These impurities do not seem to affect the light output or operating efficiency, for they are present in very minute quantities.

* Special analyses were made by Mr. H. Highriter in our laboratory.

The efficiency of such a tellurium vapor arc lamp varies over wide ranges, depending quite largely upon the power supplied to the lamp. At low energy input an efficiency of 2 to 5 lumens per watt is observed while at higher wattages

FIG. 3.



about 15 lumens per watt is attained. At extreme operating conditions lamps have been made to yield an efficiency above 40 lumens per watt. The accompanying graph, Fig. 3, indicates the rate at which the light output of two lamps of

8 mm. inside diameter and 10 cm. arc length changes when the wattage in the lamp is varied. This curve, similar to such data obtained with mercury lamps,[5] indicates the high theoretical efficiency possible and also the enormous wattage losses at the electrodes. The equation $L = 81.5(W - 27)$ is typical of such lamps. L is the lumens per cm. of arc stream, W is the watts per cm. of arc supplied to the lamp, the constant 81.5 indicates the maximum theoretical efficiency of this lamp if the wattage loss at the electrode could be neglected, while the value 27 represents the portion of watts per cm. lost at the cathode and anode and from which no light is obtained. The wattage lost at the electrodes is excessively high in this lamp, so its overall efficiency is relatively low in comparison to mercury or sodium arc lamps. The combined anode and cathode falls of potential are between 50 and 150 volts for most of these lamps, the actual values depending upon the operating conditions and the structure of the lamp. A lamp of 6 mm. inside diameter and 10 cm. arc length requires 1 to 2 amperes at 100 to 300 volts for steady operation while lamps of 8 mm. internal diameter and 10 cm. arc length have been operated satisfactorily with 2 to 3 amperes at 150 to 200 volts.

The efficiency of these lamps is very dependent upon the wave form of the supply voltage. Operated on a D.C. generator with ballast resistance, the efficiencies are appreciably higher than when the same lamps are operated on a rectifier circuit in which there is a pronounced ripple in the voltage wave. Maximum or theoretical efficiencies in which electrode losses have been neglected may be very appreciably larger or smaller than those indicated in Fig. 3, depending upon the geometry and size of lamp, and upon the supply voltage.

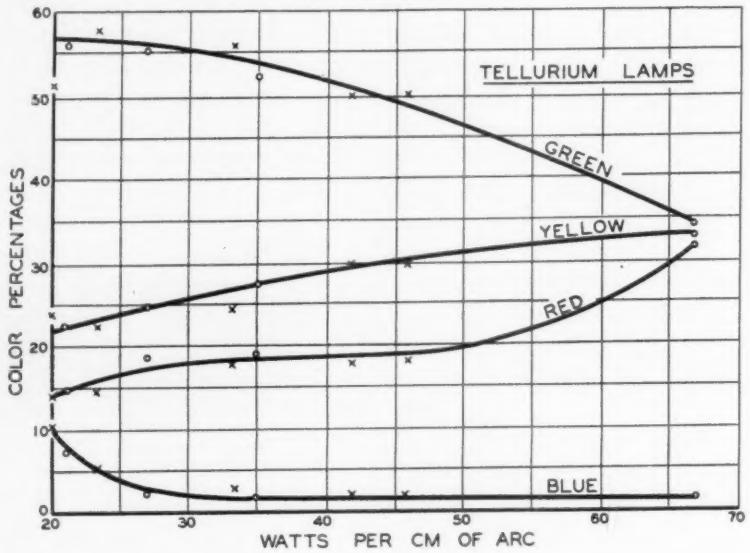
With colored glass filters an estimation of the color distribution of the lamp can be made. The accompanying table shows the distribution of light from a tellurium lamp operating at low wattages wherein the color is a bluish white and also with higher wattages supplied to the same lamp while the color is a golden yellow. These values are compared to a

[5] Marden, Beese and Meister, *Elec. Engr.*, **55**, 1186 (1936).

black body at 6000° K., a 200-watt tungsten filament lamp and a high pressure quartz mercury lamp.[6]

In Fig. 4 one can see the color variations accompanying changes in wattage supplied to the lamps. This data was

FIG. 4.



obtained from two lamps of 6 mm. and one lamp of 8 mm. inside diameter, each lamp having an arc length of about 10 cm. Various color filters were used and the wattage was varied over enormous ranges. At very low wattages the color approximates that of a black body at 6000° K., but here the efficiency is very low.

Light Distribution in Visible Spectrum.

Wave-length	Red 7200	Yellow 5950	Green 5650	Blue 4950
Source.	5950.	5650.	4950.	4000.
Tellurium low wattage	14.5	22.5	56	7.
Tellurium High wattage	32.	33.	34	1.
Black body at 6000° K	15.1	22.5	55.8	6.6
200-watt Tungsten lamp	28.5	27.5	41.5	2.5
High pressure mercury lamp	1.	43.	54.	2

[6] Marden, Beese and Meister, *Trans. I.E.S.*, **32**, 84 (1937).

CONCLUSION.

Tellurium vapor arc lamps give a continuous instead of a line spectrum ordinarily found in metallic vapor lamps, and for this reason will receive attention as a possible illuminant in the future. At present it is merely a laboratory curiosity since it must be made with pool type electrodes in a quartz envelope and requires direct current for operation. Its color changes are very pronounced as the wattage supplied to the lamps is varied. At low wattage the color is practically identical to that given off by a black body at 6000° K. This spectral color distribution makes the tellurium vapor lamp ideal for certain special applications.

OPERATIONAL REPRESENTATION OF DISCONTINUOUS FUNCTIONS.

BY

LOUIS A. PIPES,

Research Associate, The University of Wisconsin, Madison, Wisconsin

INTRODUCTION.

In many physical investigations such as the study of the behavior of electrical or mechanical systems, it is often convenient to employ operational processes.

It is the purpose of this paper to develop some operational equivalents for several commonly employed discontinuous functions of particular use in the theory of electrical networks. The method used is the Laplace Transform point of view of Heaviside's operational calculus.

THE BASIC EQUATIONS.

Following Van der Pol, *Phil. Mag.*, VIII, p. 861 (1929), we will regard $g(p)$ as the operational equivalent of $h(t)$ if $g(p)$ and $h(t)$ are related by the fundamental equation:

$$g(p) = p\int_0^\infty e^{-pt}h(t)dt, \tag{1}$$

where p is a complex number whose real part is greater than zero, and the integral is supposed to converge. It is further supposed that $h(t) = 0$ for t less than zero.

If the relation above is satisfied, we write as Van der Pol has done:

$$g(p) \doteqdot h(t).$$

It is well to mention that from the basic relation (1) we have by the Bromwich-Wagner theorem,

$$h(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty}\frac{g(p)e^{pt}dp}{p} \qquad i = \sqrt{-1}, \tag{2}$$

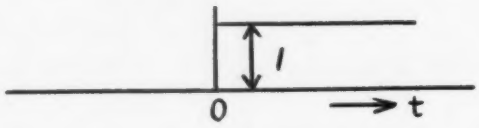
where i is the imaginary unit, e the base of the natural logarithms, and c is a positive constant such that the path of

integration in the complex p plane lies to the right of the singularities of the integrand. We have in (2) the solution of the integral equation (1).

With the aid of these fundamental formulas, the operational equivalents of several discontinuous functions will be established.

I. THE UNIT FUNCTION.

As a first example, let Heaviside's well-known unit function be considered. This function is zero if t is less than zero and equals unity if t is greater than zero. Let the unit function be denoted by $[1]$. Its graphical representation is given below.



To get the operational equivalent of the unit function we place $h(t) = [1]$ in our fundamental formula (1).

Then

$$g(p) = p\int_0^\infty e^{-pt}dt = -e^{-pt}\Big]_0^\infty = 1;$$

that is, $1 \doteqdot [1]$.

This result could easily have been anticipated from a consideration of the integral given below. This integral has the tabulated values:

$$\frac{1}{2\pi i}\int_{-i\infty+c}^{+i\infty+c}\frac{e^{pa}}{p}dp = \begin{cases} \frac{1}{2} & \text{if } a = 0, \\ 1 & \text{if } a > 0, \\ 0 & \text{if } a < 0, \end{cases} \tag{3}$$

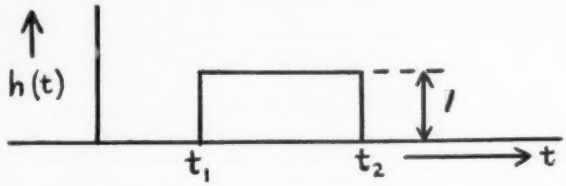
so that $[1] = \frac{1}{2i}\int_{-i\infty+c}^{+i\infty+c}\frac{e^{pt}}{p}dp$ is the representation of the unit function.

The relation (3) will be found most useful in the subsequent study.

II. A FINITE UNIT PULSE.

As a second example, let the representation of a pulse of finite duration be considered. Such a pulse is graphically

represented below and may represent, as an example, the voltage impressed on a circuit by means of a telegraph key.



A pulse will be considered whose magnitude is unity and that begins at $t = t_1$ and ends at $t = t_2$.

We choose as our $h(t)$ the function defined by:

$$h(t) = \begin{cases} 0 & t < t_1, \\ 1 & t_1 < t < t_2, \\ 0 & t > t_2. \end{cases}$$

Returning to our fundamental equation (1) we have:

$$g(p) = p\int_0^\infty e^{-pt}h(t)dt = p\int_{t_1}^{t_2} e^{-pt}dt = e^{-t_1p} - e^{-t_2p}.$$

Hence for the pulse,

$$g(p) = e^{-t_1p} - e^{-t_2p}.$$

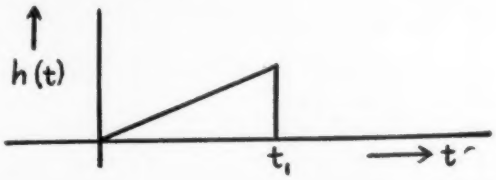
This result might also have been foreseen from (3) in that since the analytical representation of the pulse is

$$h(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{e^{p(t-t_1)} - e^{p(t-t_2)}}{p}dp$$

it may be regarded as a + unit function formed at $t = t_1$ and the subsequent addition of a negative unit function formed at $t = t_2$.

III. THE INCLINED PULSE.

Let us determine the operational equivalent of the inclined pulse given graphically below.



Let the slope of the pulse be m. Hence:

$$g(p) = p\int_0^{t_1} mte^{-pt}dt,$$

or
$$g(p) = \frac{m}{p} - \frac{m}{p}e^{-pt_1} - mt_1e^{-pt_1}.$$

Now, since $\frac{m}{p} \doteqdot mt$, this result clearly shows that the inclined pulse may be regarded as the addition of mt and a subtraction of a constant function of value mt_1 formed at $t = t_1$ and the continued subtraction of a function mt formed at $t = t_1$. The two subtracted functions cancel mt_1 after $t = t_1$ and the result is zero.

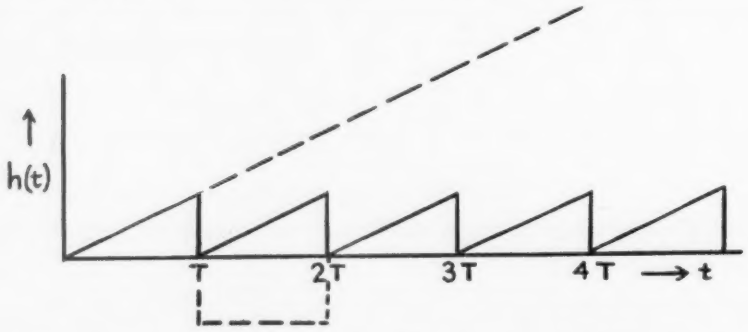
Hence if $h(t)$ represents the inclined pulse, we have the result:

$$h(t) \doteqdot \frac{m}{p}(1 - e^{-pt_1}) - mt_1e^{-pt_1}.$$

From these examples, it is easy to see that the operational equivalents of any combination of complicated pulses may similarly be obtained.

IV. SAW-TOOTH FUNCTION.

Consider the function shown below which represents a certain type of electromotive force impressed on a circuit.



The saw-toothed e.m.f. may be considered as the sum of the dotted line graphs.

If the slope of the saw-tooth be m, the sloped line may be represented operationally by m/p. At $t = T$, we must have

a negative function of constant value $-mT$ formed. The operational equivalent of such a function is $-mTe^{-pT}$. The continued addition of the negative functions represented by the dotted lines gives us the operational equivalent of the saw-toothed e.m.f. It is:

$$g(p) = \frac{m}{p} - mT(e^{-Tp} + e^{-2Tp} + e^{-3Tp} + \cdots).$$

But we have the well-known result that,

$$\frac{1}{2}\left(1 + \coth\frac{Tp}{2}\right) = 1 + e^{-Tp} + e^{-2Tp} + e^{-3Tp} + \cdots.$$

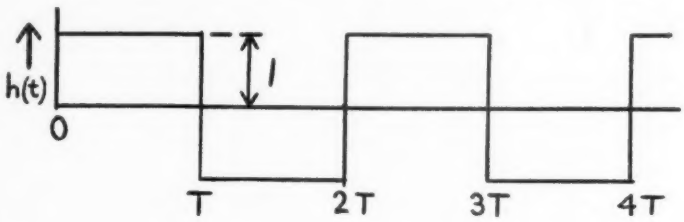
Hence:

$$g(p) = \frac{m}{p} - \frac{mT}{2}\left(\coth\frac{Tp}{2} - 1\right) \doteqdot h(t)$$

is the operational equivalent of the saw-toothed function as shown.

V. THE MEANDER FUNCTION.

Let us consider the function represented graphically below.



This function may be considered as made up of the successive addition of constant positive and negative functions formed at 0, T, $2T$, $3T$, etc. Hence:

$$\begin{aligned} g(p) &= 1 - 2e^{-Tp} + 2e^{-2Tp} - 2e^{-3Tp} + \cdots + \\ &= 2(\tfrac{1}{2} - e^{-Tp} + e^{-2Tp} - e^{-3Tp} + \cdots). \end{aligned}$$

But by a well-known result:

$$\frac{1}{2}\tanh\frac{Tp}{2} = (\tfrac{1}{2} - e^{-Tp} + e^{-2Tp} - e^{-3Tp} + \cdots).$$

Hence $g(p) = \tanh\dfrac{Tp}{2} \doteqdot h(t)$.

Heaviside's method of obtaining the operational equivalent of a function began with its Fourier expansion and the subsequent translation of each trigonometric term into its operational equivalent. In some cases Heaviside was able to sum the series and obtain a finite operational equivalent.

Let us now reverse the process and starting with the operational representation of the function, obtain its Fourier expansion.

We have for the meander function:

$$h(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{e^{pt}}{p} \tanh\frac{Tp}{2}\,dp.$$

To evaluate the integral we calculate the sum of the residues of $\frac{e^{pt}}{p}\tanh\frac{Tp}{2}$ in the p plane. The poles of this function are at $p = p_m$,

$$p_m = \frac{(2m+1)\pi i}{T}, \qquad m = 0, \pm 1, \pm 2, \cdots.$$

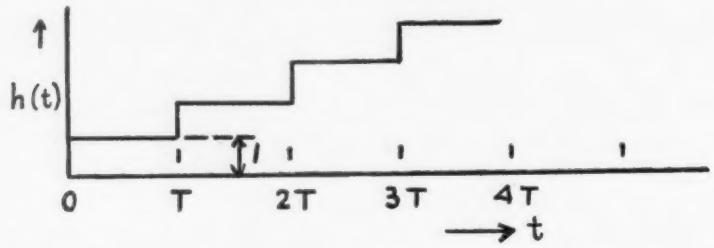
Hence, evaluating the residues at these simple poles, we obtain:

$$h(t) = \sum_{p_m} \frac{e^{p_m t}\sinh\frac{Tp_m}{2}}{p_m\frac{T}{2}\sinh\frac{Tp_m}{2}} = \frac{4}{\pi}\sum_{1}^{\infty}\frac{1}{s}\sin\frac{s\pi t}{T}, \qquad s \text{ odd}.$$

The well-known Fourier expansion of the function $h(t)$.

VI. THE STEPPED-FUNCTION.

A function which is of interest in the gradual building up of voltages is represented graphically below:



This function may be regarded as produced by the additional formation of unit functions formed at the intervals 0, T, $2T$, etc.

Hence:

$$g(p) = 1 + e^{-Tp} + e^{-2Tp} + \cdots.$$

If the function continues to build up indefinitely, we have, using the result:

$$\frac{2}{1}\left(1 + \coth\frac{Tp}{2}\right) = 1 + e^{-Tp} + e^{-2Tp} + e^{-3Tp} + g(p)$$

$$= \frac{1}{2}\left(1 + \coth\frac{Tp}{2}\right) \doteqdot h(t).$$

VII. A FUNDAMENTAL THEOREM.

Before proceeding to a discussion of curved functions it is necessary to establish a fundamental theorem:

If $g(p) \doteqdot h(t)$ then,

$$e^{-Tp}g(p) \doteqdot \begin{cases} 0 & \text{if } t < T, \\ h(t-T) & \text{if } t > T. \end{cases}$$

Proof: From the basic relation (2) we have:

$$h(t) = \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{e^{pt}g(p)dp}{p}.$$

Hence:

$$\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{e^{-Tp}g(p)e^{pt}dp}{p}$$

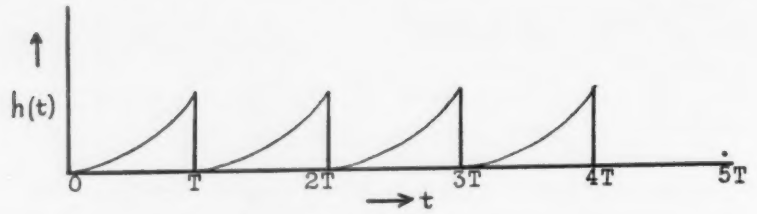
$$= \frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} \frac{e^{p(t-T)}g(p)dp}{p} = h(t-T) \quad \text{if } t > T,$$

and a consideration of the contour integral shows that it is equal to zero if $t < T$. This establishes the theorem.

This theorem is of great value in obtaining operational representations of repeated curved functions.

VIII. THE REPEATED PARABOLA.

Consider the function represented by the graph given below. The curved portion is the parabola t^2.



Let us first obtain the operational representation of only one parabolic arch, extending from 0 to T.

$$g(p) = p\int_{c-i\infty}^{c+i\infty} t^2 e^{-pt}dt$$

by the basic formula.

Integrating and substituting the limits, one obtains:

$$g(p) = \frac{2}{p^2} - T^2e^{-Tp} - (2/p^2)e^{-Tp}(pT + 1).$$

The operational equivalent of the repeated curve may be obtained by the use of the theorem in VII. Let the operational representation of the repeated curve be $g_1(p)$. Then

$$\begin{aligned} g_1(p) &= g(p) + e^{-Tp}g(p) + e^{-2Tp}g(p) + \cdots + \\ &= (1 + e^{-Tp} + e^{-2Tp} + \cdots +)g(p) \\ &= \frac{1}{2}\left(1 + \coth\frac{Tp}{2}\right)g(p). \end{aligned}$$

From this example, it is easily seen how other operational representations may be obtained.

IX. ELECTROMOTIVE PULSE ON AN *L*, *R*, CIRCUIT.

In order to give a simple illustration of the applicability of the operational representation of discontinuous functions in the theory of electric circuits, let us consider the case of a pulse of voltage applied to a simple circuit consisting of a resistance and inductance in series.

The equation satisfied by the current in such a circuit is,

$$\frac{di}{dt} + \frac{R}{L}i = \frac{E(t)}{L}.$$

We will consider $E(t)$ to be a pulse similar to the one discussed in *II*. It has a constant magnitude E and is formed at $t = T_1$ and ceases at $t = T_2$. Let us further assume that

at $t = 0$ there is an initial current flowing $i = i_0$. Proceeding in the conventional manner, we multiply both sides of the equation by e^{-pt} and integrate with respect to t from 0 to infinity. We thus obtain:

$$\int_0^\infty e^{-pt}\frac{di}{dt}dt + \frac{R}{L}\int_0^\infty e^{-pt}idt = \frac{1}{L}\int_0^\infty e^{-pt}E(t)dt.$$

Let $g(p) = \int_0^\infty e^{-pt}idt.$

Making use of the initial condition and integrating by parts, we obtain:

$$-i_0 + pg(p) + \frac{R}{L}g(p) = \frac{E}{Lp}(e^{-T_1p} - e^{-T_2p}).$$

Hence:

$$g(p) = \frac{1}{\left(p + \frac{R}{L}\right)}\left(i_0 + \frac{E}{Lp}[e^{-T_1p} - e^{-T_2p}]\right)$$

and

$$i(t) = \frac{1}{2\pi j}\int_{c-i\infty}^{c+i\infty} e^{pt}g(p)dp, \qquad j = \sqrt{-1}.$$

Evaluating the contour integral, we easily obtain:

$$i(t) = i_0e^{-Rt/L}, \qquad 0 < t < T_1.$$

$$i(t) = i_0e^{-Rt/L} + E/R - E/Re^{-R(t-T_1)/L}, \qquad T_1 < t < T_2,$$

$$i(t) = i_0e^{-Rt/L} - E/Re^{-R(t-T_1)/L} + \frac{E}{R}e^{-R(t-T_2)/L}, \qquad t > T_2.$$

The greater simplicity of solution by this method over the elementary differential equation method is to be noted. In this method we have not been troubled by the determination of arbitrary constants. The boundary conditions are automatically adjusted.

CONCLUSION.

The operational representation of discontinuous functions may easily be effected by the fundamental formulas (1) and (2). The use of such operational representation is of great utility in the Laplace Transform or operational solution of electrical and mechanical systems. Discontinuous expressions that do not admit of Fourier expansion because of lack of periodicity may readily be handled in this manner.

The Conveyor-type Scale-free Hardening Furnace.—A. R. RYAN (*General Electric Review*, Vol. 40, No. 11). A large number of the products for modern industry which are manufactured by the drill press, lathe, and screw machine, must be heat treated before they can be placed in service. This treatment must be done accurately or the product, otherwise perfect, may become worthless. The most recent type of heat treating equipment is the conveyor-type scale free hardening furnace, by means of which numerically large quantities (as differentiated from large poundage) of steel parts may be accurately hardened while retaining a clean metallic surface. The equipment consists of a refractory lined heat-insulated chamber. Inside the heating chamber, an endless-belt conveyor fabricated from heat-resisting alloys is arranged to carry material from one end of the furnace to the other. While being transported through the furnace, the material is heated and, when it reaches the end of the conveyor, it falls downward through a sealed discharge chute directly into the quench bath. A conveyor in the quench tank catches the material and removes it from the bath. The furnace is heated with electric resistors, the circuit of one of which is located at the discharge end of the conveyor to control accurately the quenching temperature. A protective atmosphere for scale-free hardening is provided by the partial burning of combustible gas.

R. H. O.

MECHANICAL SOLUTION OF ALGEBRAIC EQUATIONS.

BY

HARRY C. HART AND IRVEN TRAVIS.[1]

ABSTRACT.

The paper describes a machine for determining the real and complex roots of higher-degree algebraic equations. The principle of operation is found in the correspondence between sine wave quantities and complex numbers. The particular machine is designed for equations of the eighth degree, and finds all the roots with engineering accuracy in the space of a few minutes.

Though designed primarily with a view to determining the indicial admittance of electric networks, the machine should find utility in other fields of applied mathematics as well.

Were it possible to obtain the general solution of higher-degree algebraic equations, a machine for obtaining particular solutions would fall into the same class as the slide-rule and like instruments, being at best an aid to the computer. It has been proved,[2] however, that the general solution of algebraic equations of degree higher than the fourth cannot be obtained, and that particular solutions are the only ones possible in equations of fifth degree and higher. Therefore the solutions obtainable with such a machine are of the same degree of generality as those obtainable by any other means. Furthermore, the great amount of labor involved in known methods of obtaining such solutions by successive approximation tends to place such a machine, particularly when capable of automatic operation, in the class [3] of aids to the engineer.

[1] The device described in this paper was a group development. The method was evolved by Mr. Hart, based on suggestions made by members of the Moore School staff. Many individuals have contributed to the reduction of the method to practice. Among these are William E. Bradley, J. G. Brainerd, Carl C. Chambers, R. Shiels Graham, Donald M. Herr, Knox McIlwain, Louis Ippinger, Miles E. Nelson, Sabcho Sabeff, Gilbert Swift and C. N. Weygandt. Since Professor Travis supervised the construction of the final machine he has been asked to collaborate in the writing of this paper.

[2] N. H. Abel, "Œuvres Complètes," Christiania (Oslo), 1881; Vol. I, pp. 28–33.

[3] Calculating machines fall naturally into two different classes, depending upon the nature of the problems they are adapted to solve. The first class comprises machines or devices which merely reduce somewhat the labor of per-

Similar considerations are applicable to other types of equations, and they are in large measure responsible for the success and usefulness of the machines referred to in the footnote.

Essentially, the process of developing a machine to solve a mathematical problem is exactly the inverse of the process of determining the behavior of a machine by mathematical methods. In the latter process, daily utilized by the engineer and so familiar that it requires no justification, the component motions of the machine are symbolized by quantities and their interrelations by operators. We make sure of this correspondence at each step, solve the resulting equation by known methods, and interpret the solution as representing the behavior of the machine.[6] Our reliance on the result depends, in the last analysis, on our faith in the efficacy of mathematical processes and in the uniqueness of the stated correspondences.

In developing a machine to solve a mathematical problem, the exactly inverse process is employed. We devise or discover machine components which may be caused to behave in a manner corresponding to the mathematical quantities in our equation, and we couple these components together by means which we believe bear an exact correspondence to the operations indicated in the equation. We then set the

forming calculations which could be carried out with comparative ease without the assistance of a machine. Devices of this class, which includes the abacus, the slide rule, the adding machine, the planimeter, and the like, have been developed and produced since the dawn of history. Their chief value lies in the great number of problems which arise within their scope, rather than in the economy of labor in any given problem.

The second class comprises machines or devices for carrying out mathematical processes which would involve a *prohibitive* amount of labor if performed by other means. In certain problems, the methods and operations to be employed in reaching a solution are fully understood, but involve an amount of labor so excessive that the problems are, in effect, well nigh insoluble. By reason of the fact that the methods are understood, machines can sometimes be devised which eliminate the labor and enormously reduce the time. The steadily increasing number and importance of the problems of this character presented by modern engineering science has resulted in the successive development, during the past decade, of a number of machines of this, the second class. See, for example, V. Bush, JOURN. FRANKL. INST., **212**, p. 447, Oct., 1931; N. Minorski, *Rev. Gen. de l'Électricité*, **39**, p. 787, May, 1936; J. B. Wilbur, JOURN. FRANKL. INST., **222**, p. 715, Dec., 1936.

machine in motion and interpret some preassigned feature of its behavior as representing the solution to our problem. Our reliance on the solution again depends on our belief in the uniqueness of the stated correspondences.

The machine described below is an instance of this process, as will be seen from the description to follow.

Before coming to the operation of the particular machine, it should be stated that numerous mechanical methods have been and can be devised of obtaining the real roots of algebraic equations. Since the complex roots are usually the ones of interest, no further reference will be made to such methods. So far as the authors are aware, prior to the development of the machine described in this paper, only one mechanical method [4] has been devised which obtains all the roots, complex as well as real, of higher-degree equations. It is not generally known, and evidently did not meet with much success. It has been investigated by the authors and found to offer interesting possibilities for further development, but to be quite unsatisfactory in its present form.

The machine described in this paper was devised in 1934 at the Moore School of Electrical Engineering, University of Pennsylvania, and an experimental model, designed to handle equations of the third degree, was immediately built. Tests confirmed the theory of operation and justified further work. Since that time further work has been done and an eighth-degree machine is now in operation at the Moore School. It determines all the roots of an equation of the eighth degree in the space of about one-half hour, and with errors not greater than 2 per cent. in modulus and 1 per cent. in argument.

PRINCIPLE OF OPERATION.

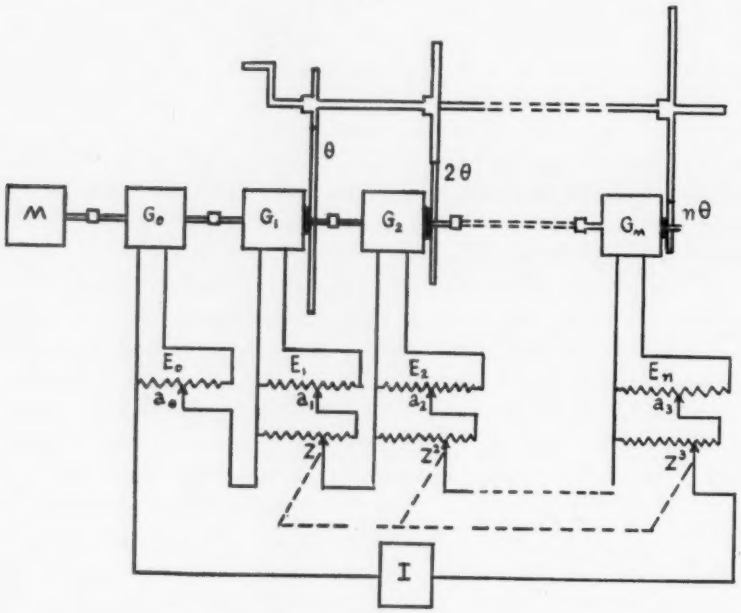
The principle of operation will now be described in connection with the essential elements of the apparatus.

Referring to Fig. 1, a set of $n + 1$ like alternating current generators (G_0, G_1, etc.) are mounted coaxially on trunnions. The rotors are directly coupled to one another, but the stators, all except one, are free to rotate independently of

[4] Felix Lucas, *Comptes Rendus*, **106**, pp. 121, 195, 268, 587, 645, 1072 (1888). See also: Russel and Wright, *Phil. Mag.*, **18**, 291; 6th Ser. (1909). Russel and Alty, *Phil. Mag.*, **18**, 802; 6th Ser. (1909).

one another. The rotors are driven together by a constant speed motor. Each stator but one, on the other hand, is separately geared, through gears of properly chosen tooth-number, to a single countershaft; the tooth-numbers are such that for a given angle of rotation of the countershaft, the "zeroth" stator remains fixed, the first rotates through an angle θ, the second through an angle 2θ, etc., and the nth through an angle $n\theta$.

FIG. 1.



The output terminals of the $n + 1$ generators are connected to a set of $n + 1$ separately adjustable potentiometers termed the "coefficient potentiometers"; and across each of these but the "zeroth" is connected a second potentiometer, whose resistance is high compared with that of its predecessor. These potentiometers, termed the "modulus potentiometers," have their movable contacts mechanically geared or coupled together, and are so designed that for a given displacement of the first from the low-voltage end, the displacement of the second is proportional to the square of that of the first,

that of the third proportional to the cube of that of the first, etc., and that of the nth one proportional to the nth power of the displacement of the first. The output terminals of this second set of potentiometers are connected in series with an indicating voltmeter.

If now the motor be started, the generators will deliver voltages of like magnitude and frequency, but of phase depending on the stator positions. Thus the voltages will be respectively of the form

$$\left.\begin{aligned} e_0 &= E\cos\omega t \\ e_1 &= E\cos(\omega t+\theta) \\ e_2 &= E\cos(\omega t+2\theta) \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ e_n &= E\cos(\omega t+n\theta). \end{aligned}\right\} \tag{1}$$

If now the movable contacts of the coefficient potentiometers be set to positions proportional to the numbers, $a_0, a_1, a_2, \cdots a_n$, the voltages appearing across the output terminals of these potentiometers will be of the form

$$\left.\begin{aligned} e_0' &= a_0E\cos\omega t \\ e_1' &= a_1E\cos(\omega t+\theta) \\ e_2' &= a_2E\cos(\omega t+2\theta) \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ e_n' &= a_nE\cos(\omega t+n\theta). \end{aligned}\right\} \tag{2}$$

These voltages are impressed on the modulus potentiometers, and as a result the voltages appearing across the output terminals of the latter are of the form

$$\left.\begin{aligned} e_0'' &= a_0E\cos\omega t \\ e_1'' &= a_1ZE\cos(\omega t+\theta) \\ e_2'' &= a_2Z^2E\cos(\omega t+2\theta) \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ &\cdot \qquad\qquad \cdot \\ e_n'' &= a_nZ^nE\cos(\omega t+n\theta). \end{aligned}\right\} \tag{3}$$

Finally, since these voltages are impressed in series on the indicating device, the voltage on the latter is

$$v = a_0E\cos\omega t + a_1ZE\cos(\omega t+\theta) + a_2Z^2E\cos(\omega t+2\theta) + \cdots + a_nZ^nE\cos(\omega t+n\theta), \quad (4)$$

which may be written

$$v = a_0E\frac{e^{j\omega t}+e^{-j\omega t}}{2} + a_1ZE\frac{e^{j(\omega t+\theta)}+e^{-j(\omega t+\theta)}}{2} + \cdots + a_nZ^nE\frac{e^{j(\omega t+n\theta)}+e^{-j(\omega t+n\theta)}}{2}$$

$$= \frac{Ee^{j\omega t}}{2}\{a_0 + a_1Ze^{j\theta} + a_2Z^2e^{j2\theta} + \cdots + a_nZ^ne^{jn\theta}\} + \frac{Ee^{-j\omega t}}{2}\{a_0 + a_1Ze^{-j\theta} + \cdots + a_nZ^ne^{-jn\theta}\}. \quad (5)$$

Denoting the first bracket by **P** and the second by **Q**, (5) becomes [5]

$$v = \mathbf{P}\frac{Ee^{j\omega t}}{2} + \mathbf{Q}\frac{Ee^{-j\omega t}}{2}. \quad (6)$$

By a well-known transformation, (6) is in turn equal to

$$v = \mathbf{P}E\left(\frac{\cos\omega t}{2} + j\frac{\sin\omega t}{2}\right) + \mathbf{Q}E\left(\frac{\cos\omega t}{2} - j\frac{\sin\omega t}{2}\right), \quad (7)$$

which, upon collecting terms, becomes

$$v = (\mathbf{P}+\mathbf{Q})E\cos\omega t + j(\mathbf{P}-\mathbf{Q})E\sin\omega t. \quad (8)$$

Let $v = 0$ at all times, which requires that both $(\mathbf{P}+\mathbf{Q})$ and $(\mathbf{P}-\mathbf{Q})$ be equal to zero. This can only be true when **P** and **Q** vanish individually.

Now the algebraic equation of the nth degree i.e., the equation to be solved, is

$$a_0 + a_1\mathbf{Z} + a_2\mathbf{Z}^2 + \cdots + a_n\mathbf{Z}^n = 0, \quad (9)$$

[5] Consistently with accepted standards, complex quantities are indicated by bold face type.

which, since **Z** is in general a complex number, may be written

$$a_0 + a_1 Z e^{j\theta} + a_2 Z^2 e^{j2\theta} + \cdots + a_n Z^n e^{jn\theta} = 0, \qquad (10)$$

where Z is the modulus of **Z**, and θ its argument.

It will be observed that the left-hand member of (10) is identical in form with the polynomial **P**, of (5) above. Therefore a null reading of the indicating voltmeter which means that **P** = 0 also means that (10), and therefore (9), is satisfied.

The method of operation will now be clear. The first set of potentiometers are set, respectively, to positions proportional to the coefficients of the equation to be solved. The stators are rotated continuously, and the second set of potentiometers moved gradually from zero to their maximum values. This is the electrical analog to tracing a spiral in the complex plane. When the indicating voltmeter reads zero, the values of Z (modulus potentiometer position) and θ (stator position) are noted.

CONSTRUCTION.

In addition to the general considerations given above, certain practical details of construction may be of interest.

Figure 2 shows a photograph of the machine in its present form. The generators employed are commercial 1/20 H.P. motors with shaft extension at each end. Their bases were sawn off and their stators trued up on the lathe and provided with two sets of slip rings. The armatures, also provided with slip rings (simply by fitting a fiber tube over the commutator and two brass rings over this, in position to register with the original brushes, which were slightly off-set), are connected to one pair of the outer slip rings, the field windings being connected to the other pair. The couplings are of the pin-and-socket disk type. A heavy cast iron base carries standards provided with trunnion bearings at the top for the stators and additional bearings at the side for the countershaft. The couplings and trunnion bearings are so designed that any generator can be singly removed for adjustment, without disturbing its neighbors.

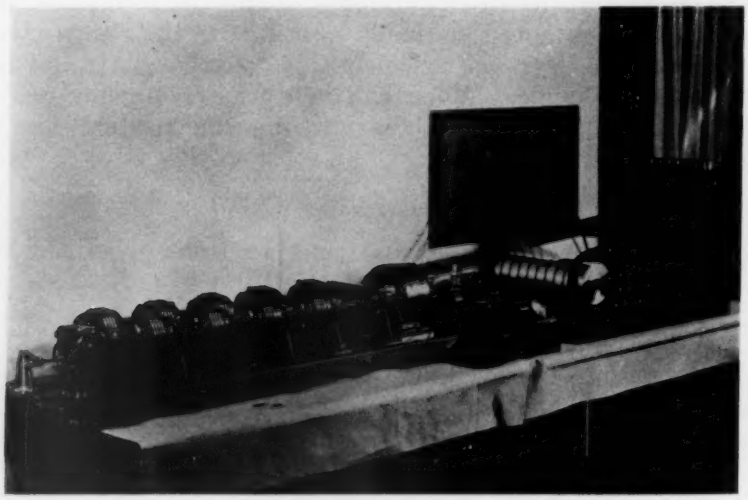
Each of the coefficient potentiometers in fact comprises two resistors in series, a large one and a small one. This was found to be necessary when it turned out that the pre-

cision of the instrument was such that a large difference in result occurred due to a shift of a single turn of wire on the coefficient potentiometer. Accordingly, a fine-adjustment potentiometer was provided in each case.

To take care of negative signs in the equation, a reversing switch is provided ahead of each of the coefficient potentiometers.

The modulus potentiometers are closely wound on bakelite rod, carefully chosen for uniformity of diameter. The

FIG. 2.



movable contacts are actuated by steel tapes, the other ends of which are wrapped around spiral cams mounted on a single shaft. The cams are cut closely [6] to the form

$$\int_0^l dl_n = kz^n,$$

where l is the length of arc of wrap, and z is the angle of rotation of the cam shaft.

[6] Practically, the cams depart slightly from this exact form due to the necessity of compensating for lateral displacement of the tape. Their outlines were therefore determined empirically, rather than by calculation.

In order to economize space it is necessary to place a limit on the size of the cams. This results in a limit on the magnitude of the roots obtainable. The limit was chosen at unity, the cams being so cut that when rotation of the shaft is complete, the arc lengths are all alike. When roots whose absolute values are greater than unity are to be investigated, the equation may be transformed by the substitution,

$$\mathbf{Y} = \frac{\mathbf{I}}{\mathbf{Z}}.$$

Utilization of the arc lengths of the cams in place of their radii greatly reduces the space required.

Though the fundamental components of the voltages balance out at the proper points, their harmonics do not. It is therefore advisable, in addition to operating the generators at very light load, to filter out substantially all trace of harmonic distortion. Since great sensitivity is also desirable, these two functions are combined in a tuned amplifier which serves as the component hitherto described as an indicating voltmeter. It is terminated in a rectifier supplying a D.C. meter, and designed to have a steeply falling sensitivity characteristic, such that though large signals do not drive the needle off scale, small ones produce a substantial deflection.

To reduce as far as possible the effects of stray disturbances, line voltage fluctuations, and the like, the coefficients are set in terms of a predetermined voltage of the machine itself, the voltage E_0 being employed for this purpose as a standard. The voltage E_0 is switched onto a precision resistor provided with a movable contact and a vernier dial, the output terminals of this potentiometer are connected to a preamplifier of widely variable grid bias, and the main amplifier is switched into connection with the preamplifier. The dial of the precision resistor is set to the value of a given coefficient and the bias reduced until a deflection of the meter in the amplifier output circuit occurs. Then, leaving the grid bias unchanged, the potentiometer representing the particular coefficient is switched into connection with the preamplifier, and its movable contact adjusted until the same deflection occurs. The process is repeated for each

coefficient. By this means, the coefficients are all set in proper proportion unless the voltage E_0 should happen to have changed during setting. Later proportionate changes in the voltage cannot affect the result.

CONCLUSION.

Machines of the type described should obviously be of great value in the calculation of the transient behavior of linear electrical and dynamical systems. The Moore School machine permits the complete solution of four-mesh electrical networks containing resistance, inductance and capacitance, and will therefore be helpful in the solution of electrical filter and similar problems, particularly in the communications field. It is anticipated that research will be undertaken along several of these lines in the near future. Refinements may of course be added to the machine such that it will operate automatically, permitting the operator to set the coefficients, put it in operation, and return to find the roots located on a polar diagram.

CONCERNING THE HERSCHEL EFFECT.

BY

FRED G. PERSON AND JULIAN M. BLAIR,

Colorado State College of Agriculture and Mechanic Arts, and the University of Colorado.

I. TEMPERATURE AND THE HERSCHEL EFFECT.

The Herschel Effect is a regression of the latent photographic image under the influence of long wave-length radiation. Although we have observed no studies concerning the effect of temperature upon the rate of the Herschel Effect, extensive and seemingly conflicting reports exist concerning the effect of temperature upon the rate of formation of density by ordinary exposures.

Abney [1] in 1884 found that heating a plate with a hot iron increased the sensitivity to light many fold. Lumiere [2] found that exposures of 300 to 400 times as long were required at liquid air temperatures to produce the same densities as exposures at room temperatures. Precht and Scheller [3] found small variation in sensitivity between − 32° C. and 90°. Daleziki [4] found a temperature coefficient of 1.05 between 7° and 64°. Zimmern [5] found a small increase in sensitivity between 20° and 80°. King,[6] on the other hand, found a 50 per cent. increase in sensitivity between 70° F. and 0° F.

Wallace [7] found that the effect of temperature upon the sensitivity was dependent upon the intensity of the exposing radiation. Webb [8] in 1935 verified these findings of Wallace.

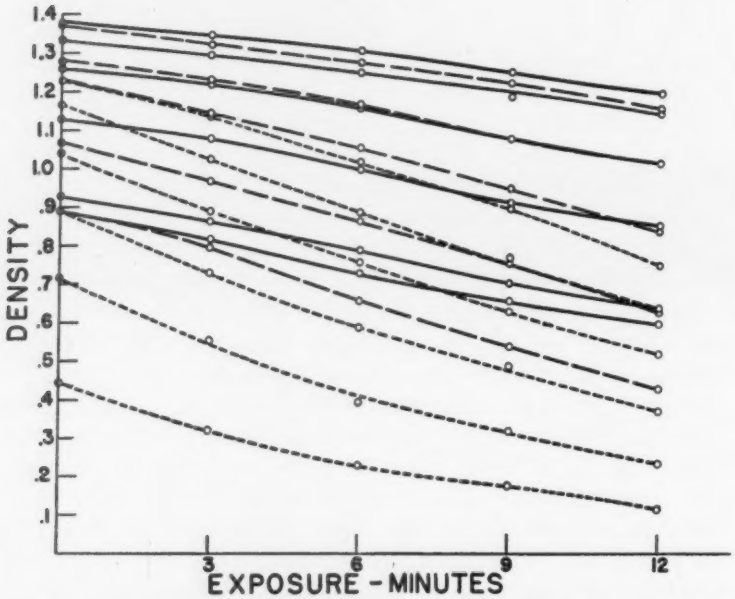
The first portion of this paper deals with the effect of temperature upon the rate of the Herschel Effect.

Different strips of a rectangular sheet of chloride paper (Convira 5) parallel to the shorter dimension were given

[1] *Phot. News*, **28**, 315 (1884).
[2] *Comptes Rendus*, **128**, 359 (1899).
[3] *Arch. wiss. Phot.*, **1**, 58 (1899).
[4] *Zeit. wiss. Phot.*, **18**, 233 (1919).
[5] *Comptes Rendus*, **174**, 453 (1922).
[6] *Photo-Beacon*, **17**, 267 (1905).
[7] *Astrophys. J.*, **28**, 39 (1908).
[8] *J. Opt. Soc. Am.* **25**, 4 (1935).

exposures of 10, 12, 14, 16, 18, and 20 seconds to white light. The longest exposure was almost sufficient to produce the maximum developable density. The whole sheet was then mounted in an electric furnace 19 cm. from a red 25 w. incandescent bulb (emitting wave-lengths 0.64 mμ and longer) mounted outside of the furnace. The illumination on the paper under these conditions will be arbitrarially called intensity 1. Successive strips of the paper parallel to the

FIG. 1.



Showing the bleaching of the latent image during exposure to red light of intensity 1. The solid lines show bleaching at 20°—the dashed ones at 50°—and the dotted ones at 100°.

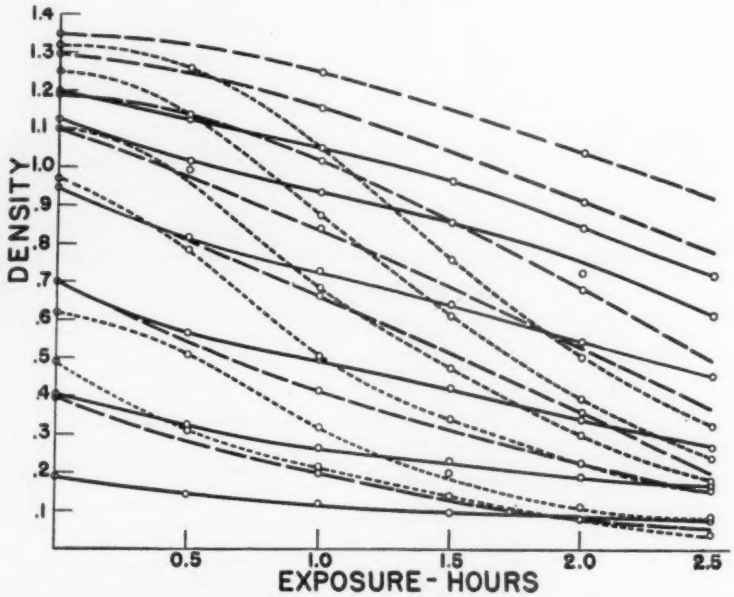
longer dimension were then given increasing exposures to the red light at specified temperatures. The first tests were made at 20° C., and others at 50°, and at 100°.

After this second exposure the paper was developed in elon hydroquinone using a brush, and finished in the usual manner. The normal reflection densities were measured with a photo-electric cell, and in Fig. 1 are plotted against the time of exposure to red light. The densities produced by the first exposures are plotted at abscissa 0. In this figure it is evident

that under these conditions the Herschel Effect is much more rapid with increasing temperatures.

The red light was moved to such a position that the intensity of illumination on the paper was 0.1 of the former value and the investigation mentioned above was repeated under this fainter illumination. The data obtained are shown in Fig. 2. Fig. 3 shows the results obtained when the relative intensity of the red light was 0.01. In the latter

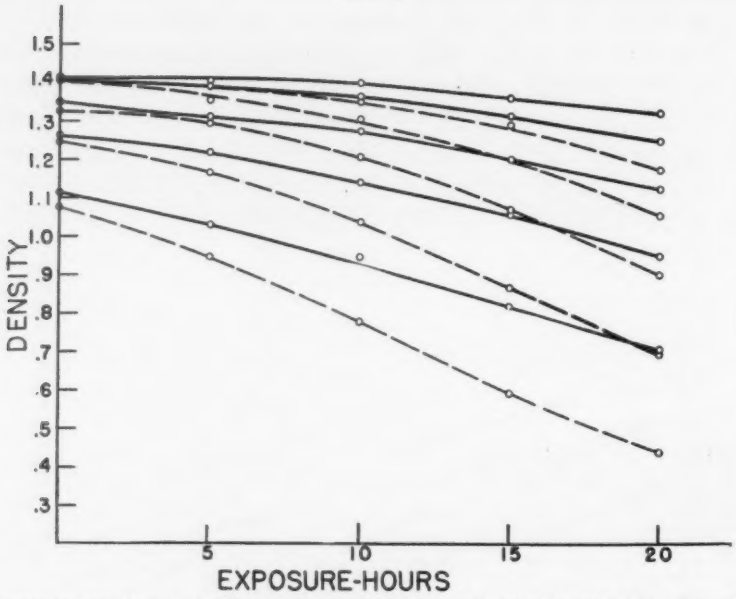
FIG. 2.



Showing the bleaching of the latent image during exposure to red light of intensity 0.1. The solid lines show bleaching at 20°—the dashed ones at 50°—and the dotted ones at 100°.

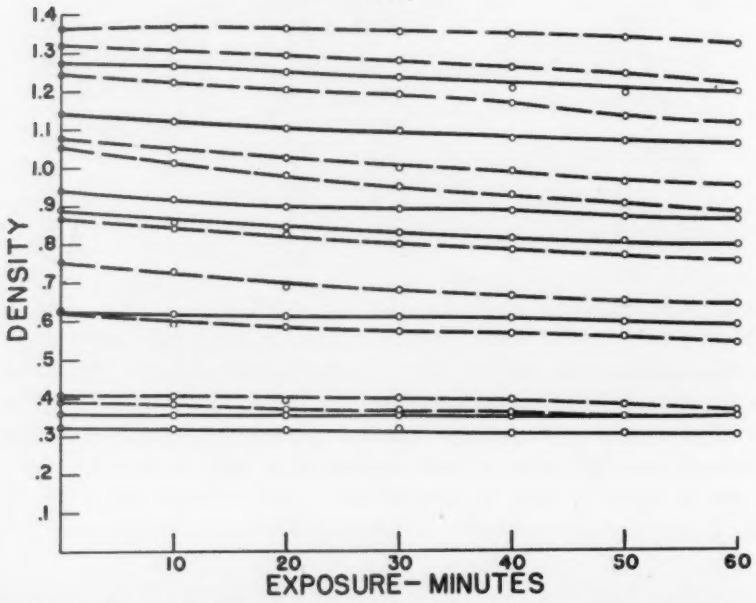
figure the data obtained after an exposure at 100° is not shown, for during these long exposures at a relatively high temperature heat alone has an appreciable effect upon the magnitude of the latent image. Such an effect might not be uniform upon all portions of a strip. The data obtained when the red light was fainter than 0.01 was complicated by regression and by the formation of developable density by such prolonged exposures to heat. To avoid an appreciable

FIG. 3.



Showing the bleaching of the latent image during exposure to red light of intensity 0.01. The solid lines show bleaching at 20°—the dashed ones at 50°.

FIG. 4.

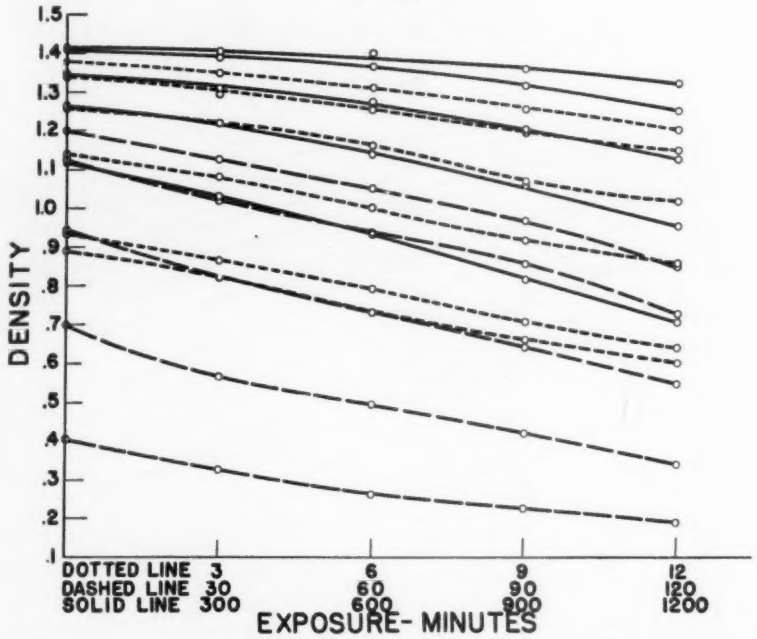


Showing the rates of the Herschel Effect at 20° (dashed lines) and at − 22° (solid lines).

effect due to simultaneous new blackening during the bleaching no data was obtained at intensities greater than 1.

The slopes of the curves in Fig. 1 at a given temperature and at a given density vary, depending largely upon the time elapsed since the beginning of the exposure to red light. However, the averages of the slopes at given densities and specified temperatures were found. An analysis of these

FIG. 5.



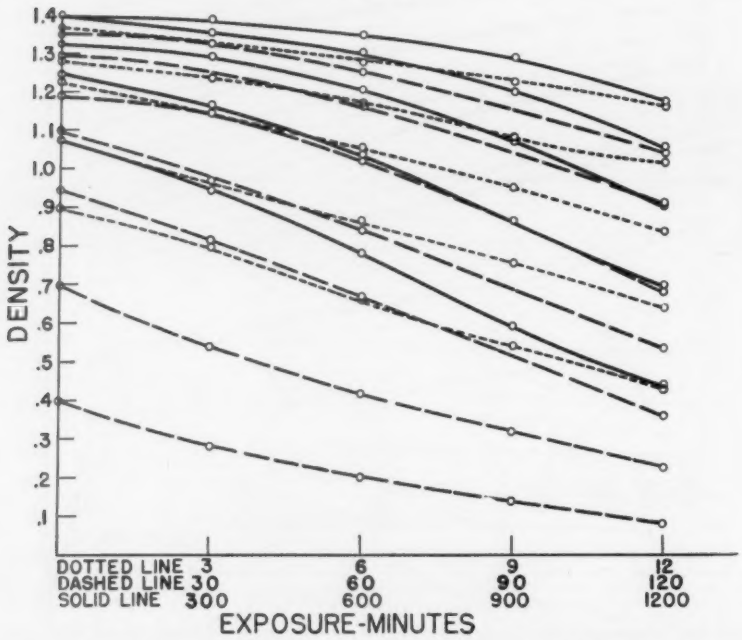
Showing the effect of intensity upon the Herschel Effect at 20°. The dotted lines show bleaching at intensity 1—the dashed lines at intensity 0.1—and the solid lines at intensity 0.01. The abscissae vary for the three families of curves by factors of ten so that $i \cdot t$ is the same for all curves at any point along the horizontal axis.

slopes indicated a temperature coefficient at intensity 1 of 1.08; at intensity 0.1 of 1.11; and at intensity 0.01 of 1.15. The term temperature coefficient is used here to mean the ratio of the velocity at a given temperature to that at a temperature 10° lower, and not in the sense suggested by Arrhenius' equation.

Similar tests were made upon Azo 5 paper at intensity 0.1 and the temperature coefficient was found to be 1.1.

Other tests were made upon Convira 2 paper. The first exposures were made as before but the second exposures were made at intensity 0.08 and at 20° in some cases and at − 22° upon other sheets. The latter temperature was that prevailing out of doors at the time. The use of artificial refrigerants was avoided because of the formation of frost under ordinary conditions. The results of these tests are shown in Fig. 4. There it is evident that the rate of bleaching is small at the lower temperature, and at a density of 0.35 there was apparently no bleaching during an exposure of 1 hr.

FIG. 6.



Showing the effect of intensity upon the Herschel Effect at 50°. The dotted lines show bleaching at intensity 1—the dashed lines at intensity 0.1—and the solid lines at intensity 0.01.

II. THE RECIPROCITY LAW AND THE HERSCHEL EFFECT.

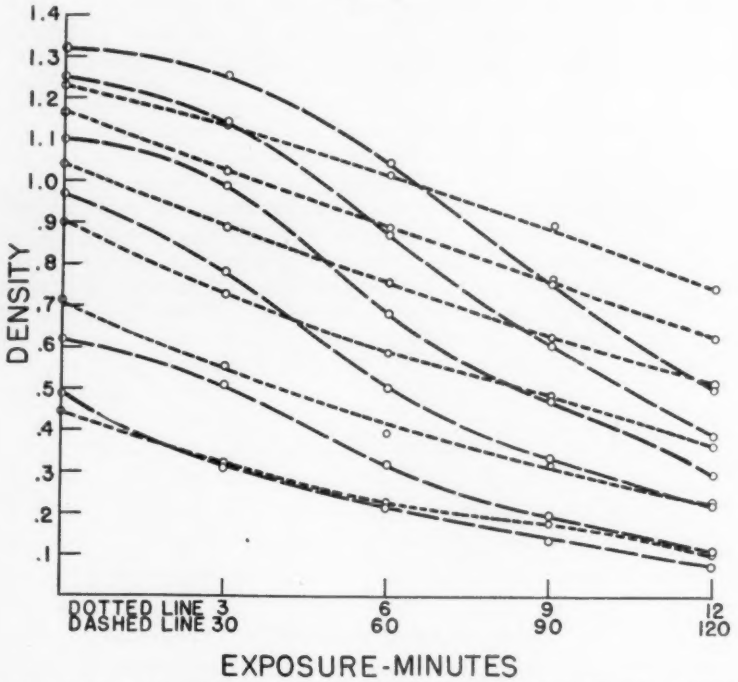
Leszynski [9] reported that he obtained the same amount of bleaching if the intensity of the red light was decreased and the time of exposure increased in the same ratio. That is,

[9] *Zeit. wiss. Phot.*, **24**, 275 (1926).

for a given $i \cdot t$ (intensity $\times$ time of exposure to red) the amount of bleaching is independent of i. Lüppo-Cramer,[10] on the other hand, found that upon desensitized emulsions fainter lights are more effective in producing the Herschel Effect than the same amount of energy in a brighter light for a shorter time.

If one assumes that in any photographic exposures (either

FIG. 7.



Showing the effect of intensity upon the Herschel Effect at 100°. The dotted lines show bleaching at intensity 1, and the dashed lines at intensity 0.1.

direct blackening or the Herschel Effect) there exist simultaneously two processes (one tending to produce density and the other to destroy it), from the observation that lower densities are obtained at lower intensities of illumination one is led to believe that a fainter light should be relatively more effective in producing the Herschel Effect.

The data already presented in Figs. 1, 2, and 3 are re-

[10] *Zeit. wiss. Phot.*, **24**, 380 (1927).

plotted in Figs. 5, 6, and 7. In Fig. 5 is collected the data obtained with light of varying intensities when the furnace was at 20°. This data shows that under these conditions the Herschel Effect increases for a given $i \cdot t$ as i decreases. In Figs. 6 and 7 are shown the data obtained at 50° and 100° respectively. From these figures we conclude: that at 20° when the intensity is reduced to one-tenth the former value the effectiveness is 1.2 times that of the brighter illumination; and at 50° it is 1.22 times; and at 100° 1.8 times.

We wish to express our thanks to Messrs Thurston, Hoagland, Pohlenz and Christy who aided us in this work.

EFFLUX OF GASES THROUGH ORIFICES—KINETIC THEORY.

BY

B. V. KORVIN-KROUKOVSKY,

Edo Aircraft Corporation.

SUMMARY.

The efflux of gases through orifices was treated heretofore on basis of adiabatic expansion, postulating the decrease of temperature, which is not observed in the facts of everyday experience. The consideration of molecular motion on the principles of the Kinetic Theory of Gases shows the possibility of the expansion of a gas flowing through an orifice without change of temperature, and permits the formation of simple quantitative relations which are in a satisfactory agreement with test data. For small difference in pressure the new expression for discharge becomes identical with Fliegner's formula. It is explained that reduction of temperature postulated by adiabatic formulæ should be understood to apply to the observer moving with stream, and that no change of temperature is registered by stationary observer. The possibility of extension of the adiabatic and of the new "kinetic" formulæ to the pressure ratios below critical is opened by the consideration of reduced number of impacts between molecules with reduction of the pressure ratio.

When a gas expands under a piston in a cylinder it does the work on the piston at the expense of the heat energy. If the process is slow enough so that enough heat can be supplied from outside and the temperature of the gas is not changed, the expansion is called isothermic. If the cylinder is insulated, and the process is sufficiently rapid so that no heat can be transmitted to the gas from the outside, the expansion is called adiabatic. In this case the heat energy is given up by the gas, and its temperature is decreased. This transformation of heat energy into mechanical work and the resultant decrease of the temperature of the gas with expansion has been so thoroughly established in thermodynamics, that no other mode of gas expansion appears to be conceivable. For this reason in study of the flow of a gas from an orifice, which is a case of the rapid expansion, it is usually taken for granted that expansion is adiabatic. So little doubt exists about it that apparently the change of the temperature has not been checked experimentally. .For instance, the Steam Nozzles

Research Committee of the Institution of Mechanical Engineers (England) [6] conducted very careful experiments on the flow of superheated steam through the nozzle, and measured the initial and final pressure of the steam, the initial temperature, the weight of steam discharged, the impact of the jet, in fact everything *except the final temperature* of the steam, which was calculated on basis of the adiabatic law.

So thoroughly has been the adiabatic expansion law ingrained into engineers that they overlooked the facts of everyday experience which show that reduction in temperature stipulated by the adiabatic expansion law does not occur in practice in case of a gas escaping through an orifice. Two simple examples will demonstrate this. Most of the machine shops have the compressed air system under 80 lbs. per sq. in. gauge pressure. According to the adiabatic law the temperature of the air escaping from such a pressure into atmosphere is determined by the relation

$$T/T_0 = (p/p_0)^{0.29} = (14.7/94.7)^{0.29} = 0.58.$$

If the initial temperature of the air was 60° F., or 520° F. Abs., its final temperature must be 302° F. Abs. or minus 158° F. The velocity of the air expanding from such a pressure is in the neighborhood of 1,500 ft. per sec., and the jet of this velocity and such a low temperature would cause instant freezing of the hand if directed on it. As a matter of fact no appreciable change of temperature can be felt. Again it is evident that if such a cooling occurred it must have caused the formation of heavy frost at any leak in piping or at valves. As a matter of fact one can never observe even a light condensation.

The other example, still more accessible to everybody, is the release of air from the automobile tire at the gauge pressure of about 30 lbs. per sq. in. In this case

$$T/T_0 = (14.7/44.7)^{0.29} = 0.71$$

and with the initial temperature of 520° F. Abs. the final temperature must be 369° F. Abs. or minus 91° F. Again such a low temperature is evidently not observed.

The observation of common everyday facts shows that there is no appreciable decrease of temperature either of the

stream itself, or of the fittings through which the air escapes. The compressed air, initially at rest, acquires the streaming motion, and apparently acquires the kinetic energy without suffering any change in the temperature and consequently in the heat energy. This paradoxical fact can be explained on basis of the kinetic theory of gases. When the air is "at rest" confined in a vessel, its molecules are in constant motion and possess the kinetic energy. Opening of an orifice merely permits the molecules to travel in one direction instead of continuously rebounding from walls and from each other. The molecules do not acquire any additional kinetic energy, their motion merely changes from the random motion into streaming motion. As there is no change in the kinetic energy, there evidently is no change in the temperature, as the temperature is the measure of the kinetic energy of the molecules.[1]

DERIVATION OF FORMULÆ.

The proof of the above hypothesis will consist in the derivation of quantitative expressions for the density, velocity, and discharge of a gas, and in comparison of the results of these expressions with experimental data.

Denote by:

M—Mass of a gramm molecule of gas.

c—Root-Mean-Square Speed of random motion of molecules in the initial state.

r—Root-Mean-Square Speed of residual random motion in streaming gas.

u—Streaming Velocity.

E_c—Kinetic energy of all molecules due to translational velocities of random motion in initial state.

E_r—Kinetic energy of all molecules in streaming gas due to translational velocities of residual random motion.

E_u—Kinetic energy of all molecules due to streaming velocity.

f—The number of degrees of freedom of molecular motion possessing kinetic energy. We will consider in this case only three translational and one, two or three rotational velocities for monatomic, diatomic or polyatomic gases respectively.

[1] Leonard B. Loeb, "Kinetic Theory of Gases," First edition, p. 12, McGraw-Hill Book Co., Inc., New York and London.

a—Area of the orifice.
a_1—Cross sectional area of the jet of gas.
p_1 and v_1—Absolute pressure and volume of gramm molecule of gas in initial state.
p_2 and v_2—Absolute pressure and volume of a gramm molecule of gas in final state.

From the law of conservation of kinetic energy we can write for streaming gas:

$$E_u = E_c f/3 - E_r f/3. \tag{1}$$

On basis of elementary mechanics we have:

$$E_u = Mu^2/2.$$

On basis of the kinetic theory of gases [2] we can write:

$$E_c = Mc^2/2 = 1.5 p_1 v_1 = 1.5RT,$$
$$E_r = Mr^2/2 = 1.5pv;$$

it must be emphasized that in this case evidently $pv \neq p_1 v_1$ as $r \neq c$.

Multiplying above expressions for E_u, E_c and E_r by 2 and substituting into Eq. (1) we get

$$Mu^2 = fRT - fpv. \tag{2}$$

From this the streaming velocity can be determined, if the quantities p and v are known. From the boundary conditions of the jet we can put at once $p = p_2$. The volume of the gramm molecule v can be determined by considering the law of the conservation of momentum.

Momentum of the jet:

$$u \times Ma_1 u/v = a_1 Mu^2/v.$$

The force producing the jet is equal to the reaction of the jet, i.e. to the differential pressure $(p_1 - p_2)$ times certain area A, as shown on Fig. 1. As the streaming velocity of the gas develops, its static pressure diminishes with the result that at the rounded edges of the orifice there is gradual reduction of the pressure from its initial value of p_1 to the final value of p_2.[3] The equivalent area A over which the

[2] L. B. Loeb, loc. cit. supra, p. 18.
[3] L. B. Loeb, loc. cit. supra, p. 374.

pressure difference can be considered as uniform and equal to $p_1 - p_2$ is larger than either actual area of the orifice a or the area of the jet a_1. Denoting the ratio A/a_1 by K we can write for the jet reaction:

$$A(p_1 - p_2) = Ka_1(p_1 - p_2).$$

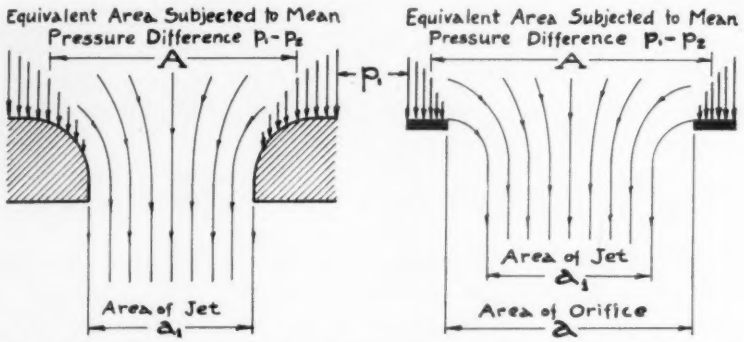
Equating the force producing the jet and the momentum of the jet we have

$$Ka_1(p_1 - p_2) = a_1Mu^2/v.$$

Cancelling a_1 and transposing we get the fundamental expression for v:

$$v = Mu^2/K(p_1 - p_2). \tag{3}$$

FIG. 1.



Distribution of pressure at the edges of orifice and the relation between orifice area and jet area for the orifice with rounded edges and the orifice in thin plate.

Substitute the above value of v into Eq. (2) and also let $p = p_2$:

$$Mu^2 = fRT - fp_2Mu^2/K(p_1 - p_2)$$

solution for u^2 yields the expression:

$$u^2 = \frac{RT}{M} \frac{fK(p_1 - p_2)}{K(p_1 - p_2) + fp_2}. \tag{4}$$

The weight discharged per second is

$$W = gMa_1u/v$$

or

$$W^2 = g^2M^2a_1^2u^2/v^2.$$

Substituting the value of v from Eq. (3):

$$W^2 = a_1^2 g^2 K^2 (p_1 - p_2)^2 / u^2.$$

Substituting the value of u^2 from Eq. (4):

$$W^2 = (a_1^2 M g^2 / RT)[K^2 (p_1 - p_2)^2 / f + K p_2 (p_1 - p_2)],$$

and finally

$$W = a_1 (M g^2 / RT)^{0.5} [K^2 (p_1 - p_2)^2 / f + K p_2 (p_1 - p_2)]^{0.5}. \quad (5)$$

For practical use it will be more convenient to express u^2 and W in terms of the pressure ratio $\beta = p_2/p_1$ rather than pressure difference $p_1 - p_2$, and also to replace the universal gas constant R and the mass of the gram molecule M by the particular gas constant B referred to the unit of weight.

Substituting in Eqs. (4) and (5) $\beta = p_2/p_1$ and $B = R/gM$ we get final expressions:

$$u^2 = gBT \frac{fK(1 - \beta)}{K(1 - \beta) + f\beta}, \quad (6)$$

$$W = a_1 p_1 (g/BT)^{0.5} [K^2 (1 - \beta)^2 / f + K\beta(1 - \beta)]^{0.5}. \quad (7)$$

In certain cases it is convenient to replace BT by $p_1 V_1$ where V_1 is the volume of gas per unit of weight. In such case

$$p_1 (g/BT)^{0.5} = (g p_1 / V_1)^{0.5}.$$

EVALUATION OF K.

For the efflux of the incompressible fluid, or for the efflux of gas under small pressure difference $p_1 - p_2$, so that compressibility can be neglected, the value of K can be obtained directly by comparison of well known energy and momentum (jet reaction) equations for the orifice of unit area:

Energy equation

$$p_1 - p_2 = \rho u^2 / 2,$$

Momentum equation

$$K(p_1 - p_2) = \rho u^2,$$

from which it follows that $K = 2$.

For a very small pressure difference we can neglect also the first term in brackets in Eq. (5) in comparison with the second term; substituting also $Mg/R = 1/B$ we can write:

$$W = a(g/BT)^{0.5}[2p_2(p_1 - p_2)]^{0.5}.$$

Evaluating for air $B = 53.34$, and introducing conversion factors in order to express a in sq. inches, p in pounds per square inch and W in pounds per minute instead of sq. feet, pounds per sq. foot and pounds per second we get:

$$W = 66(a/T^{0.5})[p_2(p_1 - p_2)]^{0.5},$$

which is the well known Fliegner's formula [9] with the coefficient increased by $3\frac{1}{2}$ per cent. It is interesting to note that this formula was developed here on basis of purely theoretical reasoning.

The value of K for larger pressure difference can be obtained experimentally for the orifices with rounded edges for which the jet area is equal to the orifice area, and K can be defined as

$$K = \text{Jet Momentum}/a(p_1 - p_2).$$

The jet momentum was measured in experiments on steam nozzles both as jet reaction [4, 5] and as jet impulse.[6] The value of K was computed from the data of these tests and was plotted on Fig. 2. The circles denote the data from the jet reaction test,[5] and crosses the data from the jet impulse tests.[7] The plot shows that K varies with the pressure ratio, and that for the range of β from 1.0 to 0.4 the

[4] G. B. Warren and J. H. Keenan, "A Machine for Testing Steam-Turbine Nozzles by the Reaction Method." The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y., Reprint No. 2001 of the paper presented at the Midwest Power Conference, Chicago, Ill., January 26 to 29, 1926, p. 44.

[5] Warren and Keenan, loc. cit. supra, Table I on p. 42 and Fig. 15 on p. 56.

[6] "Steam Nozzles Research," Proceedings Institution of Mechanical Engineers, Storey's Gate, St. Jame's Park, London, S.W.1., January 1923.

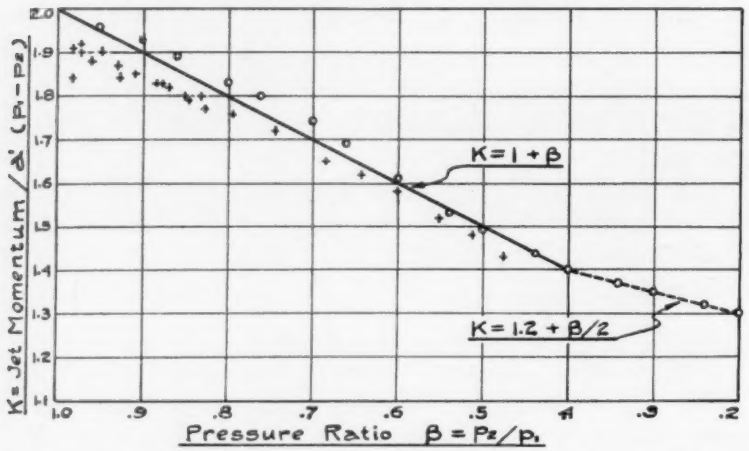
[7] "Steam Nozzles Research," loc. cit. supra, May 1925, Table 27, pp. 802 and 803.

variation can be expressed by the linear equation

$$K = 1 + \beta. \tag{8}$$

The points from the jet reaction tests approach the value of $K = 2$ with β approaching 1.0, which is in agreement with theoretical derivation of K given earlier. The points from the impulse test lie somewhat low, as there was probably unavoidable loss of energy between the jet and the impulse plate.

FIG. 2.



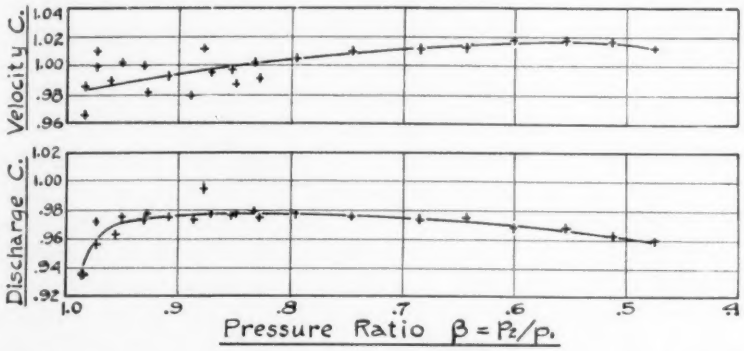
Ratio of the jet momentum to the product of the jet diameter and the pressure difference as function of the pressure ratio.

CHECK OF FORMULÆ.

Substituting the value of $K = 1 + \beta$ into Eqs. (6) and (7) and letting $a_1 = a$ for the case of the orifice with rounded edges, we have these formulæ ready for use. In order to see how they conform to the actual test data the computations of velocity and discharge were made for the superheated steam,[7] and of discharge for the air,[11] using $f = 6$ for steam and $f = 5$ for air. The results were expressed as ratios of test data to calculated data, i.e. as velocity coefficients and discharge coefficients, and were plotted on Fig. 3 for steam and on Fig. 4 (upper curve) for air. The results are quite satisfactory for steam, as the velocity is correct to within

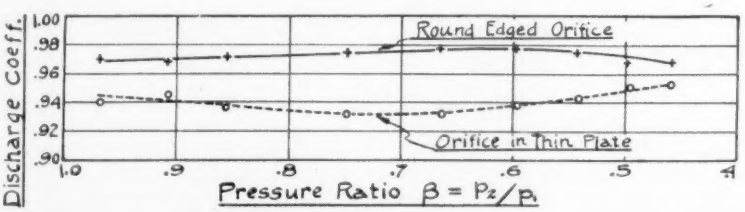
1.8 per cent., and the discharge is within 1 per cent. from its mean value of 0.97, except for very low pressure difference ($\beta < 0.97$). The agreement for the air is excellent, as the discharge coefficient is within 1/2 per cent. from its mean value of about 0.975. The fact that the curve of Fig. 4 for

FIG. 3.



Velocity and discharge coefficients based on kinetic formulæ for the superheated steam flowing through the nozzle 1¾ inch in diameter with rounded edges.

FIG. 4.



Discharge coefficients based on kinetic formulæ for the air flowing through the orifice one inch in diameter with rounded edges (shown by crosses) and through the orifice 1¼ inch in diameter in thin plate (shown by circles), giving about the same diameter of the jet.

the air is flatter than the curve of Fig. 3 for steam, indicating more consistent results, may be explained both by the fact that steam deviates more from the perfect gas in its properties, and by the fact that actual tests on air were simpler in their set up and therefore permitted greater accuracy. It may be added here that discharge coefficients mentioned above refer to the orifices of one and one and three eighth inches in

diameter. For smaller orifices the discharge coefficients have somewhat lower values.[8, 11]

ORIFICE IN THIN PLATE.

For the orifice with rounded edges the area of the jet a_1 is equal to the area of the orifice a. As the pressure ratio β decreases the ratio $K = A/a_1$ decreases as shown by Fig. 2, but as $a_1 = a$ is constant, the change must be confined to the reduction of the area A. The effect of this change in A on the discharge is fully covered by the presence of the coefficient K in the Eqs. (6) and (7), and therefore the discharge coefficient has a reasonably constant value. The situation is entirely different in case of the orifice in thin plate, as this can be seen by reference to the Fig. 1. In this case the jet area a_1 is much smaller than orifice area a, and the area A is only a little larger than a. As the ratio $K = A/a_1$ decreases the area A can decrease but little, and there must be pronounced increase in the jet area a_1. This effect manifests itself in the increase of the discharge coefficient with increase of the pressure ratio when computed by Durley's or Fliegner's formulæ.[12] From this it is evident that relation between the jet area a_1 and the orifice area a cannot be expressed by a constant factor but must be a function of the pressure ratio β or of its function K. It is found that satisfactory results are obtained by the use of the empirical relation

$$a_1 = a/K^{2/3}. \tag{9}$$

This value of a_1 in terms of a was substituted in the Eq. (7), and the discharge coefficient was computed on the basis of test data.[13] The resulting discharge coefficient is

[8] "Steam Nozzles Research," loc. cit. supra, May 1924, Table 15, pp. 496 and 497.

[9] Joseph A. Polson, Joseph G. Lowther and Benjamin J. Wilson, "The Flow of Air Through Circular Orifices with Rounded Approach," Bulletin No. 207, Engineering Experimental Station, University of Illinois, May 27, 1930, p. 7.

[10] Polson, Lowther and Wilson, loc. cit. supra, p. 40, Table 14.

[11] Polson, Lowther and Wilson, loc. cit. supra, Fig. 12, p. 23.

[12] Joseph A. Polson and Joseph G. Lowther, "The Flow of Air Through Circular Orifices in Thin Plates," Bulletin No. 240, Engineering Experimental Station, University of Illinois, January 29, 1932, Fig. 11 on p. 28.

[13] Polson and Lowther, loc. cit. supra, Table 2 on p. 22.

shown by the dotted line on Fig. 4, and is found to be within 1 per cent. of the mean value of 0.94.

COMPARISON OF KINETIC AND ADIABATIC FORMULÆ.

In the derivation of Eqs. (6) and (7) for the velocity and for the resultant discharge of the gas it was shown that kinetic energy of random motion of molecules $mc^2/2$ is reduced by the kinetic energy of streaming $mu^2/2$, and that residual kinetic energy of random motion is $mr^2/2$. In this respect the results of the new formulæ, to which we will refer for brevity as "kinetic," are similar to the results of adiabatic formulæ, which, by postulating the reduction of temperature, also show the reduction of the residual kinetic energy of molecules. It is not surprising therefore to find that results of the kinetic formulæ agree to within two per cent. to the results of the adiabatic formulæ, despite the difference in their mathematical forms. What is not generally understood and emphasized is the fact that reduction of the temperature postulated by the adiabatic formulæ *refers to the observer moving with the stream*. For such an observer the square of the molecular velocity is decreased from u^2 to r^2, in our notation, and the corresponding reduction of the temperature is observed. For the stationary observer, however, the kinetic energy of the molecules remains constant, as $c^2 = u^2 + r^2$, and the temperature therefore also remains constant.

EXTENSION OF FORMULÆ TO PRESSURES BELOW CRITICAL.

From the above discussion it follows also that kinetic and adiabatic expressions for the discharge are alike in that they both have a well defined maximum when the final pressure p_2 is about one half of the initial pressure p_1. For the lower values of the pressure p_2 the discharge theoretically diminishes rapidly due to rapid reduction of theoretical density of the gas. In practice this is not found to be the case, as the discharge is found to remain approximately constant. The adiabatic formula for the discharge

$$M = a\left\{\frac{2gk}{k-1}\frac{p_1}{V_1}\left[(p_2/p_1)^{2/k} - (p_2/p_1)^{(k+1)/k}\right]\right\}^{0.5}$$

contains no evident provision which can explain this dis-

crepancy, as the value of k originally derived from cylinder-piston experiments is found to be essentially constant for large degree of expansion. Frequently stated explanation that pressure in the throat of the orifice remains constant and approximately equal to one half of the p_1 when p_2 falls below this value is untenable, as it explains the fact that discharge remains constant, but does not explain the fact that velocity continues to increase at the same time.

The kinetic Eqs. (6) and (7) are more general in that they contain two coefficients K and f, the variation of which can explain the fact that velocity continues to increase, while the discharge remains essentially constant for pressures below critical. The Fig. 2 shows that abrupt change in K occurs for superheated steam at $\beta = 0.4$. The substitution of values of K shown by dotted line on Fig. 2 into Eq. (3) for density in connection with the observed values of the velocity u yields the calculated values of specific volume corresponding to within 1 per cent. to the observed values, as determined by the obvious relation

$$V = au/W,$$

where u is the observed velocity, and W is the observed discharge.

The Eqs. (6) and (7) for velocity and discharge, which contain also the coefficient f, are improved by the above change of the values of K, but are *both* brought in agreement only by the reduction of the value of f for superheated steam from 6 for $\beta > 0.4$ to about 5 for $\beta = 0.2$. It will be remembered that f was defined as the number of degrees of freedom of molecular motion possessing kinetic energy, i.e. three translational plus the appropriate number of rotational velocities. In making this definition it was obviously assumed that complete equipartition of energy takes place. This in turn involves the assumption that sufficient number of impacts between molecules takes place in order to permit complete exchange of their kinetic energies. Now, as the pressure ratio decreases, the number of impacts per second decreases both due to the increase of the distance between molecules, and due to the reduction of the residual velocity of random motion r. At the same time the increase of the

streaming velocity u reduces the time available, and it is likely that below certain value of β the complete equipartition of energy can no longer be attained, and the effective value of f is thereby reduced.

In applying the same principles to the adiabatic formulæ we have to postulate that index k, which is the function of f,[3] and which is constant for relatively slow speed of cylinder-piston experiments, may become a function of the pressure ratio in case of the expansion of a gas escaping through an orifice.

New Types of D.-C. Transformers.—For many years it has been the dream of the electrical engineer to produce and use a practical direct current transformer. In this connection it is interesting to note the paper by C. C. HERSKIND in *Electrical Engineering*, Vol. 56, No. 11. It describes two new types of direct current transformers using grid-controlled mercury arc rectifiers for commutating the direct current. They perform the same function on a d.-c. system as does the usual transformer on an a.-c. system. The two types are the constant-current d.-c. transformer and the constant-potential d.-c. transformer. The former consists of a 3 phase transformer having two coils per phase, three capacitors, one connected across each phase; six mercury-arc rectifier tubes for commutating the current; two d.-c. reactors, one in the input and the other in the output circuit, for maintaining a smooth current wave. The development is based upon a new circuit which was invented by Mr. C. A. Sabbah. It possesses unique operating characteristics. A constant current d.-c. transformer of 40 kw. capacity has been factory tested by connecting it to a constant voltage source, using the output to drive a d.-c. motor. The motor was held at any desired speed by adjusting the grid control. On another test the transformer connections were reversed and it was forced to pump power back into the supply, that is, to regenerate. The constant-current relationship has been proved by these tests. The constant-potential apparatus is of similar construction with some changes. It also tested satisfactorily. The new principles involved will undoubtedly prove useful in the development of apparatus for various rectifier applications, particularly those involving inverter operation.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

GALLONAGE TABLES FOR HORIZONTAL CYLINDRICAL TANKS.

Horizontal cylindrical tanks with flat ends are largely used in the petroleum oil industry. E. L. Peffer of the Bureau's Weights and Measures Division has prepared tables so that the contents of completely and partially filled tanks may readily be obtained corresponding to the inside measurements.

The table shows the volume, in gallons, of a section 1 inch in length, for tanks of various diameters filled to various depths. The total volume of liquid in a tank filled to a given depth can be obtained by multiplying the tabulated volume per inch in length, for a given diameter of tank and depth of liquid, by the length of the tank, in inches.

This publication, Circular C416, is obtainable from the Superintendent of Documents, Government Printing Office, at 5 cents a copy.

DANGERS OF PLUG FUSES.

The bridging of electric fuses is a long-standing evil and has resulted in many fires and some casualties, as this action destroys the protection with which electric circuits are supposed to be provided against overloads and short-circuits. A paper prepared by Morton G. Lloyd, chief of the Bureau's section on safety codes, for publication in the Proceedings of the International Association of Electrical Inspectors, deals only with the plug fuse and recites about 130 instances of fires which would probably have been prevented if the plug fuse in the circuit had been permitted to function in the normal way. Eight fatalities are cited where persons have lost their lives in fires brought about by a condition of bridged fuses or the substitution of a fuse of too large capacity.

Attention is called to the new non-tamperable type of plug fuse which it is not practicable to bridge internally,

* Communicated by the Director.

and if bridged at all it must be by external means which will then be readily visible. The different sizes of this type of fuse differ in construction, so that they are not interchangeable. The use of such fuses is recommended by the 1937 edition of the National Electrical Code.

ELECTRICAL THERMOMETERS FOR AIRCRAFT.

Electrical thermometers for aircraft use possess two important advantages; they are remote indicating and they can be constructed to have less time lag than other types.

At present, thermoelectric thermometers are quite generally used on airplanes to measure the temperature of the engine cylinder heads, a service for which they are eminently suited, since the thermocouple is small and can be easily attached so as to make good thermal contact.

In the flight testing of aircraft, the Bureau of Aeronautics of the Navy Department uses resistance thermometers to measure the air temperatures. In this case a low time lag is important because measurements must be made when the temperature is changing rapidly, as is the case when the airplane is climbing or descending. The distant indicating feature is also essential because it is necessary to place the temperature sensitive element at some distance from the engine and its exhaust.

In operating airships it is necessary to know the superheat, or the difference in temperature of the lift gas and the air, for which purpose electrical thermometers of either the thermoelectric or resistance type are well adapted. Superheat meters must be of the electrical type in view of the long distances of the temperature sensitive elements from the indicator in the control car of the airship.

Technical Report 606, prepared with the financial assistance of the National Advisory Committee for Aeronautics, contains a description of these instruments, and data on their design and performance. The resistance thermometer and superheat meters therein described were developed at the Bureau for the Bureau of Aeronautics of the Navy Department. Copies of this report are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

MOISTURE CONTENT OF TEXTILES UNDER CONSTANT DRYING CONDITIONS.

The following is an abstract of a statement given by James G. Wiegerink, research associate on textile drying, U. S. I. T. R. at the annual meeting of the U. S. Institute for Textile Research in New York on November 12:

The first step in the textile drying research program in progress at the Bureau for the U. S. Institute for Textile Research is to determine the moisture content of textiles under constant drying conditions. The range of conditions to be studied at first includes: Temperatures from room to 300° F., relative humidities from 1 to 95 per cent. for temperatures up to 212° F., and to the maximum relative humidities obtainable at atmospheric pressure for temperatures between 212° and 300° F., air flows up to ½ cubic foot per minute in a chamber of 2½ cubic feet capacity.

The new equipment for studying the moisture relations of textiles is now being constructed. Means are provided in this equipment for measuring the rates of drying of twelve samples under the varying conditions of temperature, relative humidity and air-flow, as well as the final moisture contents at equilibrium.

The textiles selected for this study by the administration committee include "grey" cotton, boiled-off cotton, mercerized cotton, clothing wool, carpet wool, raw silk, boiled-off silk, viscose rayon, cupra-ammonium rayon, and acetate. These textiles are to be studied after "purification" by extraction with suitable solvents, and also as received. The preparation of the textiles for study is well advanced.

The second step in the drying study will be to correlate the moisture contents of the textiles at various temperatures and humidities with their physical and chemical properties. This part of the program will be concerned with the limiting conditions beyond which the textiles will be damaged in drying and with the optimum conditions for the different textiles.

IMPROVED APPARATUS FOR MEASURING THE THERMAL TRANSMISSION OF TEXTILES.

The measurement of the transfer of heat through textile fabrics is an ever important problem. Garments, bed cloth-

ing, and the like, vary in "warmth." Cool fabrics are produced for use in summer and warm ones for winter. Manufacturers would like to know the thermal transmission of the fabrics they produce and consumers are asking for more information about the textiles they buy, including information about the thermal transmission.

New apparatus for measuring thermal transmission of textiles has been designed and built in the Bureau's Textile Section by Richard S. Cleveland. With it, the speed of testing is increased considerably over that with previous equipment without sacrifice of accuracy.

The fabric to be tested is laid upon an electrically heated hot plate. Loss of heat from the plate except upward through the fabric to the air above it is prevented by electrically heated guard plates. A hood is placed over the fabric to prevent disturbance by air currents during the test. When a steady state is reached, the energy required to maintain the hot plate at body temperature or some other chosen temperature is observed.

The regulation of temperatures is essentially automatic and little attention is required of the operator except during the 15 minutes a test is actually in progress. Seven tests can be made in an eight hour day including the time required to bring the apparatus to a steady state. Results are reproducible to within about 1 per cent. A complete description of the apparatus will be published as RP1055 in the December number of the *Journal of Research*.

SIMPLIFICATION OF SIZES OF MACHINE, CARRIAGE AND LAG BOLTS.

A new Simplified Practice Recommendation, R169–37, Machine, Carriage, and Lag Bolts, became effective on November 1, 1937.

This recommendation was developed by the American Institute of Bolt, Nut, and Rivet Manufacturers, and establishes a simplified schedule of stock-production sizes for square- and hexagon-head machine bolts, square-neck carriage bolts, and lag bolts. The schedule consists of four tables giving the stock items of maximum demand and those least frequently used. The satisfactory results accomplished

through the establishment, in 1927, of Simplified Practice Recommendation R60, covering packaging of carriage, machine, and lag bolts, prompted the industry to undertake the present project establishing standard sizes of these bolts.

The schedule of recommended stock-production sizes is based on a comprehensive study made by the Committee on Standards and Technical Practices of the American Institute of Bolt, Nut, and Rivet Manufacturers. This committee sent a questionnaire to the manufacturers to ascertain the variety in sizes of bolts produced, and to determine from analysis of the production and sales records the sizes most frequently used and, therefore, those which can be produced in anticipation of a known demand.

Prior to its final circularization to manufacturers, distributors, and users for acceptance, a preliminary draft of the proposed recommendation was submitted by the Institute to a representative group of bolt manufacturers for their consideration and approval or comment. An analysis of the replies received indicated that the companies approving the proposal constitute about 72 per cent. of the firms manufacturing such bolts, and 91 per cent. of the total volume of business in these products.

According to an estimate of the proponent organization, the adoption of this simplified practice program will effect a reduction from 896 to 584 sizes of bolts of the types covered, or an elimination of approximately 35 per cent. This substantial reduction in number of sizes to be produced for stock should create material savings through reduced costs of production and distribution. Moreover, consumers will be assured of prompt shipment of orders, as they will know which sizes are readily available from manufacturers' or distributors' stocks.

A permanent standing committee, representing the interests of manufacturers, distributors, and users, has been appointed to maintain this recommendation abreast of current conditions and best practice in the industry. The chairman of this committee is Harry C. Graham, chairman of the Committee on Standards and Technical Practices, American Institute of Bolt, Nut, and Rivet Manufacturers, Cleveland, Ohio.

In addition to the simplified list of stock items, the printed issue will include a brief statement of the development of the project, the membership of the standing committee, and a list of organizations and firms that have accepted the recommendation.

Until the printed recommendation is available, free mimeographed copies may be obtained from the Division of Simplified Practice, National Bureau of Standards, Washington, D. C.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, DECEMBER 15, 1937.

The regular monthly meeting of The Franklin Institute was called to order at 8:30 o'clock by the President, Mr. Philip C. Staples. He stated that the minutes of the previous meeting had been published in the December issue of the JOURNAL, and if there were no changes, they would be approved as printed. There were no objections and the minutes were therefore declared as approved.

The President then called upon the Secretary who presented the following statement concerning the additions to membership since the last meeting: Institute: Active Members, 5; Museum: Associate Members, 12; Student Members, 19—a total of 36.

In accordance with ARTICLE IV, Section 4 of the By-Laws the following nominations were made for officers and managers for the term beginning January 1938:

President
(to serve one year)
Philip C. Staples

Vice-Presidents
(to serve one year)
Walton Forstall
W. Chattin Wetherill
S. S. Fels

Treasurer
(to serve one year)
Benjamin Franklin

Members of the Board of Managers
(to serve three years)
G. H. Benzon, Jr.
G. H. Clamer
Clarence L. Jordan
L. H. Kinnard
Conrad N. Lauer
Richard T. Nalle
Charles Penrose
Samuel M. Vauclain

(to serve one year)
William Fulton Kurtz

The Secretary called attention to the James Mapes Dodge Christmas Lectures which are scheduled for the afternoons of December 27, 28 and 29. Dr. Dayton C. Miller, of Cleveland, Ohio, will speak on Electrostatics.

The President then introduced Dr. Ellice McDonald, Director of the Biochemical Research Foundation of The Institute, who presented his Report on the work of the Foundation during the past year. He described some of the work of the fifty-five members of the staff who are doing research upon problems connected with disease and processes of disease. He gave some interesting information on a medicinal substance that has been discovered to have direct effects upon the liver, preventing liver necrosis and curing many liver conditions. He also described the cyclotron, an apparatus only recently completed in the laboratory, by which it is possible to produce and study the new radio-active substances. These are being studied as an alternative for radium and X-rays in the treatment of cancer. A number of other studies were also described. The subject was illustrated by lantern slides.

After a discussion the Chairman extended the thanks of the audience to the speaker, and the meeting adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 10, 1937.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 10, 1937.

DR. WINTHROP R. WRIGHT *in the Chair.*

The following report was presented for final action:

No. 3023: Process for Preparation of Columbium and Tantalum.

This report recommended the award of an Edward Longstreth Medal to Clarence W. Balke, of Chicago, Illinois, "In consideration of his scientific work in chemistry and metallurgy which resulted in the development of processes for the production and commercial utilization of Columbium and Tantalum."

JOHN FRAZER,
Secretary to the Committee.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 8, 1937.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 8, 1937.

DR. WINTHROP R. WRIGHT *in the Chair.*

The following report was presented for final action:

No. 3033: Method and Apparatus for Casting Pipes Centrifugally.

This report recommended the award of an Edward Longstreth Medal to Frederick C. Langenberg and Norman F. S. Russell, of Edgewater Park, New Jersey, "In consideration of the development of means for reducing the rate of cooling of iron pipe cast by the centrifugal process in externally cooled metal molds."

Minute on the Death of Mr. Clifford W. Bates.

The Committee on Science and the Arts of The Franklin Institute records with deep regret the death of its valued and faithful member, Mr. Clifford Whitman Bates, on December 4, 1937, at the Presbyterian Hospital, Philadelphia.

Mr. Bates was elected a member of the Franklin Institute February 8, 1922, and a member of the Committee on Science and the Arts in February, 1923, on which Committee he served continuously until his death. He was a member of the Louis E. Levy Medal Committee for a number of years. He served as a member of the Library Committee continuously from February, 1926, until his death and was Chairman of this Committee for two years beginning March, 1928.

His scholarly attainments and broad scientific knowledge enabled him to be of great assistance in furthering the work and purposes of the Committee on Science and the Arts.

Be It Resolved, Therefore, that this minute be spread upon the Committee's records in tribute to Mr. Bates, and a copy of it be sent to his family.

JOHN FRAZER,
Secretary to the Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M. 674 readers made use of the facilities during the twenty-five days of November.

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Forschungsinstitut der Čechoslovakischen Zuckerindustrie. Bericht für das Jahr. 1935–36. Band 39. 1936.

GILMORE, A. B. The Cuba Sugar Manual. 1937.

BOOK REVIEWS.

PRINTING IN THE AMERICAS, by John Clyde Oswald. 565 pages, illustrations, 17 × 24 cms. New York, The Gregg Publishing Company, 1937. Price $7.50.

This book is the result of a thorough search through the literature, an accurate knowledge of the subject, coupled with the skill of a historian. In the foreword the author explains the base upon which it was written and the gaps in the history of printing which are filled by the present work. He states that Isaiah Thomas of Boston first published his History of Printing in 1810 which was followed by a second edition in 1874 appearing in the Transactions and Collections of The American Antiquarian Society. The latter contained corrections and additions which however were not complete, also it made no attempt to bridge a period of nearly two-thirds of a century that had elapsed. Since that time no single volume attempts to tell the story as a whole. This is the reason for the book at hand.

The story begins from the earliest times in the Americas. Only eighteen years after the New England Shore was settled, Matthew Daye printed the first sheet. This fact alone is of interest when considering the comparatively short period whence these people set foot in a bleak wilderness to the use of a printing press and education. The story does not always progress chronologically but groups activities, in pertinent places, of various members of the family of printers. One of these groups is the Franklin family. Those who have read the autobiography of Benjamin Franklin will recall that others than Benjamin were printers. In the book at hand this family and their work are well covered. It should be noted, however, that the author states that the *Saturday Evening Post* was started in Philadelphia in 1821. The cover page as will as the editorial page of each Post states "Founded A.D. 1728," probably implying that it is a con-

tinuation of the *Pennsylvania Gazette* which began in 1728. The correctness of either the author or the Post seems to be a point in question.

The book does not limit itself to printing in the United States. As its name implies it covers all of the Americas. These are the countries comprising North, South, and Central America as well as the West Indies. It is well written and weaves into the story historic events of the different periods.

R. H. OPPERMANN.

RECENT ADVANCES IN GENERAL CHEMISTRY, by Samuel Glasstone. 430 pages, 14 × 21 cms. Philadelphia, P. Blakiston's Son & Co., 1936. Price $5.00.

A review of the author's book on Physical Chemistry appears elsewhere in the JOURNAL. It is intended that the book at hand be a companion to that on Physical Chemistry as it covers fields on the borderline between physical chemistry and inorganic and organic chemistry according to the author's classification. The objects of the two books are about the same and the methods of exposition are similar.

This book starts with a review of atomic disintegration and the discovery of new particles and unsuspected phenomena such as artificial radioactivity, which are of chemical interest. Atomic weights of the lighter elements are also mentioned in this connection. Statistical methods are then described which are unique in the respect that they can frequently be applied to reactions involving molecular fragments and unstable free radicals not capable of direct chemical investigation. This subject represents one of the most remarkable advances in theoretical chemistry.

Ortho- and para-hydrogen is a subject of which a great deal may be heard in the future. Its treatment here is worthy of consideration. Deuterium, the discovery of the heavy isotope of hydrogen, electron diffraction by gases and vapors, solubility, the mechanism of reactions in solution, acid-base and salt catalysis, and simple organic free radicals are other divisions of the book.

Like its companion, this book will serve the chemist in bringing up-to-date a knowledge of the subjects covered.

R. H. OPPERMANN.

RECENT ADVANCES IN PHYSICAL CHEMISTRY, by Samuel Glasstone. Third edition, 477 pages, 14 × 21 cms. Philadelphia, P. Blakiston's Sons & Co. Inc., 1936. Price $5.00.

This book was originally written with a purpose to bridge the gap between journal literature and the textbook. That was the first edition in 1931. Another edition appeared in 1933 and now the 1936 edition is at hand. So it is obvious that the purpose is carried onward.

Perhaps the most important advance in chemistry is that which has permitted chemical reactions and the structure of molecules to be studied from a new viewpoint. This is the electronic theory of valency. Appropriately, the author has chosen to commence his work with a short introduction to it. He examines the theory of Kossel and that of Lewis, then proceeds to lead the reader through explanations of electrovalency and covalency, etc. The application of quantum mechanics to problems of valency and molecular structure are extensively reviewed and rightly so for this is likely in the future to add further important contributions to chemistry. A somewhat simplified outline of the methods used is

given in conformation with the broad title and purpose of the book but the work does point out the molecular-orbital view in the treatment of valency. Resonance is given an interesting account.

Sugden's Parachor, as an attempt to discover physical properties of compounds which are additive functions of their chemical compositions, is then described as well as suggestions of others. A number of interesting applications of the parachor are examined including the structure of benzene, quinone, and certain nitrogen compounds. Under the subject of dipole moments much remarkable information of a very recent nature is recorded. Considerable space is devoted to the subject of molecular spectra. Here, because of the many difficulties involved in the interpretation of the results of the study of various types of band spectra, the treatment is an elementary introduction to certain aspects of the subject although a chemist may obtain an idea of the lines along which progress has been made.

The subject of homogeneous gas reactions is reviewed and it is shown that what was thought was homogeneous are really heterogeneous. The differences of reactions are examined. Special treatment is given of the three aspects which have helped very considerably in the elucidation of the mechanism of photochemical reactions. They are the law of photochemical equivalence, the application of band spectra knowledge which was previously mentioned, and a study of the kinetics of the process. In dealing with the properties of surfaces, the author covers, among other things, the spreading of oils, the Gibbs adsorption equation, surface films, surface potentials, and the activated adsorption theory. In the latter part of the chapter on heterogeneous catalysis a number of factors have been examined, all or some of which may have an influence in catalytic reactions involving gases. The last chapter of the book is devoted to the subject of strong electrolytes.

The author covers well the subjects that he classes under the title of physical chemistry and the purpose of the work is accomplished. The work should be helpful to chemists desiring to be brought up-to-date in the topics covered.

R. H. OPPERMANN.

THE CHEMISTRY OF NATURAL PRODUCTS RELATED TO PHENANTHRENE, by L. F. Fieser. Second Edition, 456 pages, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1937. Price $7.00.

This American Chemical Society Monograph is in its second edition, the first having been published in 1936. So great has been the activity and interest in one year's time in this subject that the author has deemed it advisable to publish a second edition before such time as an extensive revision of the text may be called for. And since the first edition was exhausted within a few months of publication date the second edition may serve to satisfy present and additional demands. Only minor changes have been made in the original text.

The book begins with a treatment on the chemistry of phenanthrene and some instances of the occurrence of phenanthrene and hydrophenanthrene derivatives, then proceeds through chapters on resin acids, cancer-producing hydrocarbons, sterols and bile acids, sex hormones, heart poisons, and saponins. It is essentially an extensive review of the literature and it examines closely the formulae and structure of the natural products related to phenanthrene. There are 337

pages of text and some 90 pages of appendix. The latter contains six chapters covering the more recent literature up to January 1937. It includes references to over 300 papers published in 1936, as compared to about 200 citations to papers published in 1935. Some 50 papers are reviewed which were not previously included. There is an extensive subject as well as author index which should add much to the value of the book.

The work is a comprehensive account of the remarkable disclosures of recent research in this essentially new branch of organic or biological chemistry.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 602. Wind-Tunnel and Flight Tests of Slot-Lip Ailerons, by Joseph A. Shortal. 25 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 15 cents.

The slot-lip ailerons developed by the N. A. C. A. consist of a flap-type spoiler with an adjoining continuously open slot. The ailerons were developed in an investigation of the delayed response, or lag, of spoiler-type lateral controls. Tests of these slot-lip ailerons were made on wing models in the 7- by 10-foot wind tunnel, on a Fairchild 22 airplane in the full-scale wind tunnel and in flight, and on the Weick W1-A airplane in flight.

The tests showed that, although the slot-lip ailerons did not have the lag normally associated with plain spoilers, they were rather slow in developing the full amount of rolling moment and therefore imparted a sluggish motion to the roll of the airplane. The tests in the full-scale tunnel showed that the drag due to the open slot was excessive, but later tests in the 7- by 10-foot tunnel revealed that this drag could be somewhat reduced by modifying the slot shape.

In spite of their disadvantages, the N. A. C. A. slot-lip ailerons exhibited certain characteristics that are desirable for airplanes in which safety and simplicity of operation are considered of greater importance than high performance and a great degree of maneuverability. The slot-lip ailerons permit the use of a full-span flap; the slot may extend the angle-of-attack range with stability in roll; and the ratios of yawing moment to rolling moment are such as to be particularly satisfactory for the two-control operation of an airplane.

Report No. 604. Pressure-Distribution Measurements at Large Angles of Pitch on Fins of Different Span-Chord Ratio on a 1/40-Scale Model of the U. S. Airship "Akron," by James G. McHugh. 20 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

Pressure-distribution measurements on a 1/40-scale model of the U. S. airship "Akron" were conducted in the N. A. C. A. 20-foot wind tunnel.

The measurements were made on the starboard fin of each of four sets of horizontal tail surfaces, all of approximately the same area but differing in span-chord ratio, for five angles of pitch varying from 11.6° to 34°, for four elevator angles, and at air speeds ranging from 56 to 77 miles per hour. Pressures were also measured at 13 stations along the rear half of the port side of the hull at one elevator setting for the same five angles of pitch and at an air speed of approximately 91 miles per hour.

The maximum pressures recorded on the leading edge of the fins, for pitch angles up to 20°, were approximately the same for all fins tested regardless of span-chord ratio. At angles of pitch above 20° the maximum fin pressures increased with decreasing span-chord ratio. A negative pressure of 13 times the dynamic pressure of the undisturbed air stream was measured on the fin of lowest span-chord ratio at a pitch angle of 34°. The pitching moment contributed by the after portion of the hull increased with pitch until, at the maximum angles tested, it was approximately equal to the moment contributed by the fins. The normal force on the fin and the moment of forces about the fin root were determined. The results indicate that, ignoring the effect on drag, it would be advantageous from structural considerations to use a fin of lower span-chord ratio than that used on the "Akron."

Report No. 607. Spinning Characteristics of the XN2Y-1 Airplane Obtained from the Spinning Balance and Compared with Results from the Spinning Tunnel and from Flight Tests, by M. J. Bamber and R. O. House. 19 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

A 1/10-scale model of the XN2Y-1 airplane was tested in the N. A. C. A. 5-foot vertical wind tunnel and the six components of the forces and moments were measured. The model was tested in 17 attitudes in which the full-scale airplane had been observed to spin, in order to determine the effects of scale, tunnel, and interference. In addition, a series of tests was made to cover the range of angles of attack, angles of sideslip, rates of rotation, and control settings likely to be encountered by a spinning airplane. The data were used to estimate the probable attitudes in steady spins of an airplane in flight and of a model in the free-spinning tunnel.

The estimated attitudes of steady spin were compared with attitudes measured in flight and in the spinning tunnel. The results indicate that corrections for certain scale and tunnel effects are necessary to estimate full-scale spinning attitudes from model results.

Report No. 608. Stress Analysis of Beams with Shear Deformation of the Flanges, by Paul Kuhn. 19 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

The fundamental action of shear deformation of the flanges is discussed on the basis of simplifying assumptions. The theory is developed to the point of giving analytical solutions for simple cases of beams and of skin-stringer panels under axial load. Strain-gage tests on a tension panel and on a beam corresponding to these simple cases are described and the results are compared with analytical results. For wing beams, an approximate method of applying the theory is given. As an alternative, the construction of a mechanical analyzer is advocated.

Report No. 610. Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnel, by Eastman N. Jacobs, Robert M. Pinkerton, and Harry Greenberg. 35 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 15 cents.

A recent investigation of numerous related airfoils indicated that positions of camber forward of the usual location resulted in an increase of the maximum

lift. As an extension of this investigation, a series of forward-camber airfoils has been developed, the members of which show airfoil characteristics superior to those of the airfoils previously investigated.

The primary object of the report is to present fully corrected results for airfoils in the useful range of shapes. With the data thus made available, an airplane designer may intelligently choose the best possible airfoil-section shape for a given application and may predict to a reasonable degree the aerodynamic characteristics to be expected in flight from the section shape chosen.

For airfoils of moderate thickness, the optimum camber position was found to correspond to that of the N. A. C. A. 23012 section. A discussion is included concerning the choice of the best thickness and camber for full-scale applications depending on specific design conditions. Data to assist in the choice of the optimum section for a design using split flaps were obtained by testing some of the better sections with trailing-edge split flaps.

Report No. 611. Wind-Tunnel Investigation of Tapered Wings with Ordinary Ailerons and Partial-Span Split Flaps, by Carl J. Wenzinger. 9 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1937. Price 10 cents.

An investigation was made in the N. A. C. A. 7- by 10-foot wind tunnel to determine the aerodynamic properties of tapered wings having partial-span flaps for high lift and ordinary ailerons for lateral control. Each of two Clark Y wings, tapered 5 : 1 and 5 : 3, was equipped with partial-span split flaps of two lengths and with ordinary ailerons extending from the outboard ends of the flap to the wing tips. Measurements of wing forces and moments and of aileron hinge moments were made for the two conditions of flaps neutral and deflected.

With split flaps of equal length both wings had practically the same $C_{L_{max}}$. If 30 per cent. of the flap outer span were removed for the installation of ailerons, a reduction in $C_{L_{max}}$ of the tapered wings with flaps might be expected of the order of 4 to 7 per cent.

Ailerons of the same span were found to give higher rolling-moment coefficients together with greater adverse yawing-moment coefficients on the 5 : 3 tapered wing than on the wing tapered 5 : 1. In addition, ailerons of the same span on the tapered wings tested gave greater rolling-moment coefficients and smaller adverse yawing-moment coefficients at the same lift coefficient when the partial-span flaps were deflected than when they were neutral.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, TRANSACTIONS, Volume 124, Institute of Metals Division, 1937. 398 pages, tables, illustrations, 16 × 23 cms. New York, Institute. Price $5.00.

This volume is the eleventh of a series constituting the official proceedings of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers. It deals with nonferrous metals and includes papers presented at Cleveland in October 1936 and in New York in February 1937. This year there has been an addition to the many names of distinguished men who have given lectures before the Institute. It is Dr. R. S. Hutton whose paper on refractories appears in this volume and was presented in New York. There are some twenty-one other papers with their accompanying illustrations, curves and tables in-

cluded in this volume. Four of these deal with precipitation-hardening, a very important subject.

R. H. OPPERMANN.

EXPLORING THE HEAVENS, by Clyde Fisher. 223 pages, plates, illustrations, 14 × 22 cms. New York, Thomas Y. Crowell Company, 1937. Price $2.00.

Here is another book on popular astronomy. Its author is a man not only outstanding as an astronomer but one having had much experience in presenting the subject in a non-technical way to the layman. Dr. Clyde Fisher is now in charge of the Hayden Planetarium in New York. The book contains some of the substance of most of his popular talks in this planetarium and elsewhere.

It is always interesting when reading a book of this kind to note just what the author states with regard to that most fascinating question as to the possibilities of the existence of life on other planets, particularly on Mars. In this book the answer is to be found early, in the explanations on the earth and neighbor worlds. The atmosphere of Mars is examined. How this is done and the findings are fully explained. All this is a presentation of fact as it is known. There follow briefly the conjectures of H. G. Wells and Lord Dunsany as to what the inhabitants of Mars must look like. This interweaving of imaginations with facts can be found throughout the book. It adds color to the story, strengthening its appeal, to the average reader.

The book is complete with explanations of the sun, the moon, the seasons, comets, meteors, stars, constellations, and the aurora. After all this there is a chapter entitled "A Glimpse of Relativity." There is listed and briefly explained Einstein's three experimental tests which the astronomer could apply to verify the theory of relativity, and the results are described which confirm much of the theory. The title of the chapter is truly indicative of its contents, for the understanding of the theory of course requires the use of mathematics, and a layman's interest is not so intense as to warrant its use. The chapter does give some notion what it is all about, however.

The last part of the book is devoted to a brief description of the four planetaria in America, those at Northwestern University, The Franklin Institute, Griffith Park in Los Angeles, and the Hayden Planetarium in New York City.

The book is a shining example of supreme ability in presenting a fascinating subject to the average reader in an interesting way.

R. H. OPPERMANN.

Of the present-day American group of popularizers of astronomy, probably no name is better known than that of Clyde Fisher. His work in visual education at the American Museum of Natural History, with which he has been connected since 1913, combined with his deep interest in astronomy, made it very logical that the Museum should send him to Germany, in 1925, to investigate the educational possibilities of the then newly-developed Zeiss projection planetarium. His account of this trip, as told to various scientific groups, provided the first full information given to American astronomers about these useful instruments. Chicago, Philadelphia and Los Angeles were fortunate enough to precede New York in having them in operation, but the Hayden Planetarium, of the American Museum, was finally opened in 1935. Dr. Fisher, of course, was selected to head it, and in the two years since the Hayden Planetarium has been highly successful.

In addition to speaking before many audiences in the Planetarium, his lectures before other organizations have gained him many friends, who were always glad to hear his skillful descriptions of astronomical work. And now comes a book from his pen, which will reach an even larger audience.

"Exploring the Heavens" is an excellent contribution to the splendid list of popular books on astronomy that have appeared in the last few years. Each one of these books, though excellent in all respects, has particular points in which it is notable. The really interested layman would do well to read several, and to compare the approach of different authors. To this reviewer it seems that in Dr. Fisher's work the most significant chapters are those dealing with meteor craters and with eclipses, both fields in which the author has been particularly active. The passages devoted to the Estonian craters, which have very recently been proven of meteoric origin, is the first full account in English of these objects.

With a book so excellent throughout, however, it is very difficult to select outstanding parts. Starting with chapters devoted to the Earth and neighbor worlds, the Sun, the Moon, eclipses, the seasons, comets and meteors, he comes to the origin of the solar system. The latest ideas concerning this controversial subject are discussed in a manner that will be understandable to all. Then come the stars and nebulae, followed by chapters devoted to the constellations of spring, summer, autumn and winter. "The Astronomer's Workshop" is a concise account of the principal instruments of research. Another chapter tells of the polar aurora, then comes a discussion of some of the more popular aspects of relativity, and the concluding chapter describes the Hayden Planetarium.

Throughout, the book is beautifully illustrated, both with half-tone plates, and with numerous diagrams in the text. With a book written so well, and of such usefulness to the layman who wants a clearer insight into astronomy, it is most unfortunate that the publishers have marred their work by the omission of an index.

JAMES STOKLEY.

CHEMICAL ENGINEERING CATALOG, 1937, twenty-second annual, edition. The Process Industries' Catalog, collected, condensed and standardized data on equipment, machinery, laboratory supplies, heavy and fine chemicals and raw materials used in the industries employing chemical processes of manufacture with Classified Indexes of such equipment and materials, carefully cross-referenced and A Technical and Scientific Books Section, cataloging and briefly describing a practically complete list of books in English on chemical and related subjects. 1034 pages, illustrations, 20 × 28 cms. New York, Reinhold Publishing Corporation.

The twenty-second edition of this useful publication has recently come from the press. After more than twenty years it is hardly necessary to bring it to the attention of the chemists, they all are very familiar with it. All the useful and valuable features of recent editions have been retained and corrected. The Trade Name Index is most convenient and The Technical and Scientific Book Section has been brought up-to-date. The volume is well illustrated and carefully printed.

R.

SUNSPOTS AND THEIR EFFECTS, by Harlan True Stetson. 201 pages, plates, illustrations, 14 × 21 cms. New York, McGraw-Hill Book Company, Inc., 1937. Price $2.00.

Now that the Sun is near the time when its spots are most numerous, there has been a great increase of interest in possible relationship between these solar whirlwinds and conditions on Earth. Ever since 1843, when the German druggist, Samuel Heinrich Schwabe, of Dessau, noticed that these spots varied over a period of slightly more than a decade, scientists, economists and others have sought to connect their waxing and waning with terrestrial conditions. Some suggestions have seemed to savor of the superstitious ideas of astrology, but many of the correlations are so striking that it is impossible to dismiss them lightly.

Undoubtedly there is a connection between what is happening on the Sun, and on the Earth. How extensive this connection is, whether one is the cause of the other or whether both are the result of some still unknown underlying cause, is the problem which many scientists, notably Dr. Stetson himself, are trying to solve. The time is particularly ripe for a summary of our present facts and ideas. In this book Dr. Stetson has made such a resumé, which will not only be useful to astronomers, but will, because it is so simply and clearly written, inform the layman.

Very properly, the author refrains from dogmatism. In the preface which he calls a "forewarning," he states that if he "appears to be noncommittal in his interpretation of some of the more startling presentations, it is because a scientist cannot by nature be otherwise. On the other hand, I have refrained from condemning interpretations where evidence is still scanty, for thus to condemn appears to me as unscientific as to make positive statements where complete evidence is wanting."

Individual chapters are devoted to the relation of Sun-spots to human behavior, growing things, radio (largely known as a result of Dr. Stetson's own investigations), weather and business. For obvious reasons, the latter relationship is one that has recently attracted attention. Since 1925 such things as building contracts, sale of automobiles, as well as general business activity, have followed the Sun spots very closely. As a working hypothesis, the suggestion is made that changes in the Sun's radiation of ultraviolet light, which is known to vary with the spots, may have an effect on human beings through an increase in vitamins in the plants which they eat, and, directly, on the functioning of the endocrine glands. This in turn, affects the temperament of individuals, and this would influence mass psychology with its moods of optimism and pessimism. Since buying and selling reflect confidence or anxiety on the part of the buying public, their temperament has a direct effect on the stock market and on business in general.

In the latter part of the book, some of the less frankly speculative material is presented, such as the well-known correlation between solar variations and rainfall, as well as with terrestrial magnetism. Other chapters are devoted to the cause and possible prediction of spots. Several half-tone plates of the Sun and its features (some made by Mr. I. M. Levitt, of The Franklin Institute staff, at the Cook Observatory) and a number of graphs in the text, are valuable additions. An appendix gives a very useful table of Sun spot numbers for each month from 1749 to the present, thus providing the interested reader with the raw material

to make his own studies of the effects of these spots. Evidently in an effort to make the book seem more informal, the publishers have chosen to hamper its value by omitting the index.

JAMES STOKLEY

PUBLICATIONS RECEIVED.

American Institute of Mining and Metallurgical Engineers, Transactions, Vol. 125, Iron and Steel Division. 602 pages, plates, illustrations, tables, 15 × 23 cms. New York, Institute, 1937. Price $5.00.

Lubricating Greases: Their Manufacture and Use, by E. N. Klemgard. 873 pages, tables, illustrations, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1937. Price $15.00.

New Frontiers of the Mind, by J. B. Rhine. 275 pages, plates, 14 × 21 cms. New York, Farrar & Rinehart, Inc., 1937. Price $2.50.

A Handbook for Testing Extra-Sensory Perception, arranged and edited by C. E. Stuart and J. G. Pratt, with a foreword by J. B. Rhine. 96 pages, 13 × 20 cms. New York, Farrar & Rinehart, Inc., 1937. Price $1.75.

Experimental Physics, by Samuel Robinson Williams. 158 pages, illustrations, tables, 20 × 28 cms. Boston, Ginn and Company, 1937. Price $1.00.

Illinois State Water Survey, No. 31. Preliminary Data on Surface Water Resources. 155 pages, 15 × 23 cms. Urbana, Illinois, State Water Survey Division.

Mellon Institute. Addresses at the Exercises and Science Symposium during the Dedication of the New Building, May 6 and 7, 1937. 71 pages, 15 × 23 cms. Pittsburgh, Pennsylvania, The Eddy Press Corporation.

Canada, Department of Trade and Commerce, Dominion Bureau of Statistics, Census of Industry, General Manufactures Branch. Report on the Distilled Liquor Industry in Canada, 1936. 10 pages, tables, 22 × 28 cms. Ottawa, Minister of Trade and Commerce, 1937. Price 25 cents.

Bell Telephone Laboratories, Monographs: B-1005, A Multiple Unit Steerable Antenna for Short-Wave Reception, by H. T. Friis and C. B. Feldman. 77 pages, illustrations. B-1007, Carrier Telephone Systems—Application to Railroad Circuits, by H. A. Affel. 12 pages, illustrations. B-1010, Purified Rubber for Electrical Insulation, by A. R. Kemp. 18 pages, illustrations. B-1011, The Structure of Langmuir-Blodgett Films of Stearic Acid, by L. H. Germer and K. H. Storks. 8 pages, illustrations. B-1012, Some Fundamental Experiments with Wave Guides, by G. C. Southworth. 16 pages, illustrations. B-1013, Light Signals on Moving Bodies as Measured by Rods and Clocks, by Herbert E. Ives. 25 pages, illustrations. B-1014, The Dependence of Hearing Impairment on Sound Intensity, by John C. Steinberg and Mark B. Gardner. 29 pages, illustrations. B-1015, Relation Between Loudness and Masking, by Harvey Fletcher and W. A. Munson. 25 pages, illustrations. B-1016, Paper as a Medium for Analytical Reactions—I, by Beverly L. Clarke and H. W. Hermance. 8 pages, illustrations. B-1017, Molecular Rotation in Crystalline Disubstituted Ethanes, by Addison H. White and S. O. Morgan. 29 pages, illustrations. B-1018, Separation and Determination of Impurities in Lead—I, by Beverly L. Clarke,

Leland A. Wooten and J. D. Struthers. 8 pages, illustrations. B-1019, High-Speed Vulcanization of Rubber, by A. R. Kemp and J. H. Ingmanson. 20 pages, illustrations. B-1020, Coupling Between Parallel Earth-Return Circuits under D.C. Transient Conditions, by K. E. Gould. 15 pages, illustrations. B-1021, The Origin and Development of Radiotelephony, by Lloyd Espenschied. 23 pages, illustrations. B-1022, Transoceanic Radiotelephone Development, by Ralph Bown. 12 pages, illustrations. B-1023, Sound Propagation in Ducts Lined with Absorbing Materials, by L. J. Sivian. 15 pages, illustrations. B-1024, Directional Ferromagnetic Properties of Metals, by R. M. Bozorth. 33 pages, illustrations. B-1025, Magnetic Properties of Single Crystals of Silicon Iron, by H. J. Williams. 11 pages, illustrations. Physical Theory of the Electric Wave-Filter, by George A. Campbell. 34 pages, illustrations. Accident Prevention in the Bell System, by W. P. Elstun. 18 pages, illustrations. On Loaded Lines in Telephonic Transmission, by George A. Campbell. 23 pages, illustrations. 20 pamphlets, 15 × 23 cms. New York, Bell Laboratories.

National Advisory Committee for Aeronautics, Aircraft Circulars: No. 209, Fairey "Battle" Medium Bomber Airplane (British), an All-Metal Low-Wing Cantilever Monoplane. 11 pages, illustrations. Technical Notes: No. 619, Compression-Ignition Engine Performance at Altitudes and at Various Air Pressures and Temperatures, by Charles S. Moore and John H. Collins, Jr. 38 pages, illustrations. No. 621, Pressure Drop Across Finned Cylinders Enclosed in a Jacket, by Vern G. Rollin and Herman H. Ellerbrock, Jr. 27 pages, illustrations. No. 622, Flight Tests of an Airplane Showing Dependence of the Maximum Lift Coefficient on the Test Conditions, by H. A. Soulé and James A. Hootman. 15 pages, illustrations. No. 623, Maximum Forces Applied by Pilots to Wheel-Type Controls, by William H. McAvoy. 26 pages, illustrations. No. 624, Performance Characteristics of Venturi Tubes Used in Aircraft for Operating Air-Driven Gyroscopic Instruments, by Harcourt Sontag and Daniel P. Johnson. 27 pages, illustrations. 6 pamphlets, 20 × 26 cms. Washington, Committee, 1937.

CURRENT TOPICS.

I. C. Fire-Fighting.—(*Railway Age*, Vol. 103, No. 13.) As extra safeguards to freight and to roadside property, all switch engines and several road engines on the Illinois Central are now equipped to serve as fire fighters at a moment's notice. This fire engine fleet consists of 350 locomotives in service in terminals and other congested areas on the railroad. Each locomotive carries its own supply of water together with a specially treated cotton, rubber-lined hose with a nozzle and necessary connection, all of which can be attached quickly. A stream of water can be thrown 60 feet at the rate of 100 gal. a minute. The tender on each locomotive has a capacity of from 8,000 to 10,000 gal. of water.

R. H. O.

Effect of Water Wheels on Fish Studied.—(*Engineering News Record*, Vol. 119, No. 13.) The first comprehensive test of the effect of revolving water wheels on fingerling salmon was conducted recently by the Oregon State Fish and Game Commission at the Cazadero Plant of the Portland Electric Company. A total of 1,700 three inch chinook salmon were introduced into the penstock in three separate runs. It was concluded from the test that in this particular wheel there would be a loss of 50 per cent. of all the fish passing through it. The wheel is a 5,000 hp. reaction turbine operating on a head of 130 feet at 360 r.p.m. It was pointed out in the report by Dr. H. B. Holmes of the Army Engineers that different types of wheels would have a varying severity on fish passing through them. The wheel at Cazadero is of the type that would fall midway between the extremes in severity.

R. H. O.

Metallic Catalyst Converts Town Gas into Gasoline.—(*Gas Age*, Vol. 80, No. 7.) At a recent meeting of the Institute for Physical and Chemical Research, Dr. Genitsu Kita of Kyoto Imperial University, Japan, described his improved process, by which ordinary town gas is converted into gasoline. About 180 grams of the fuel is obtained from one cubic meter of gas, it is claimed. The reactions, which take place at ordinary atmospheric pressure at a temperature of 200 deg. C., are accelerated by a special catalyst composed of nickel, cobalt, manganese, and uranium. The process incorporates some features of the Fischer system, employed in

Germany, but is more effective as the Fischer system produces only 153 grams from one cubic meter of gas.

R. H. O.

Mt. Shasta "Mud" Flows Require Line Change on S.P.—G. TILESTON. (*Railway Age*, Vol. 103, No. 16.) The Southern Pacific Railroad's Cascade line skirts the lower slopes of Mt. Shasta, a huge volcanic cone rising from a plateau 4000 feet above sea level to a height of 14,181 feet. Streams of water flowing down the mountain carry a large amount of solid material. The unusual character of the flows, which came almost without warning and which deposited approximately 350,000 cubic yards of material submerging as much as 1000 feet of track, raised the question of their origin. It was discovered that sliding rock and pumice are constantly finding their way into the stream courses, this movement being enhanced by the increased rate of erosion of the slopes which has accompanied the destruction of the forests that formerly covered them. Moreover it was found that masses of loose rock from the top slopes of Mt. Shasta are constantly feeding into the glaciers, the individual pieces being reduced in size by the movement of the ice and snow and later discharged at the mouth of a glacier to form moraines. As time goes by the moraines become larger and the slope becomes steeper. The eroding power of water flowing over these slopes are washed into the streams. The suddenness of the flow of water, it was concluded, was due to a cloudburst over the top of the mountain, which was of short duration and was confined to as little an area as two and one-half square miles. With the knowledge of the cause and origin of the troublesome flows the railroad was able to make repairs and take corrective measures.

R. H. O.

Foundation Exploration in Deep Water.—A. L. DOW in *Engineering News Record*, Vol. 119, No. 16, describes one of the most remarkable deep water explorations ever attempted which was carried on during the fall and winter of 1935–36 as a preliminary to the then projected tidal power development on Passamaquoddy Bay in Maine. The floor of the ocean upon which 6 rock fill dams were to be constructed is of marine clay with a maximum depth to rock of 150 feet. The exploration work was undertaken to determine the character and depth of this clay and the character of the underlying rock. Adverse conditions to be overcome in addition to the depth of the water were a maximum tide range of 28 feet with tidal current in excess of 8 knots per hour, wind velocities up to 60 miles per hour, waves 6 feet high, and at times, dense fog.

For drilling operations, ships were moored by means of six anchors for each ship varying in size from 5000 to 13,500 lb. Ingenious methods were used for supporting the drilling spud so as to make it possible to compensate for changes in the elevation of the barge due to tide or for lateral movement due to wind or waves. Holes were drilled on three range lines. one along the center of each damsite and one 500 feet each side of the dam. The holes were staggered at 500 ft. intervals. Efforts were made to lay out the work so that it progressed from shallow to deep water with steadily increasing lengths of spuds. Samples were taken which according to specifications were not less than 4⅞ in. in diameter. Great stress was laid upon getting the samples to the soil laboratory in an undisturbed condition. Despite adverse weather conditions the work was carried on successfully with no loss of men or equipment and no serious accidents.

R. H. O.

Columbium-Bearing Steel Has Many Favorable Properties.—W. D. WILKINSON, JR., states in the *Oil and Gas Journal*, Vol. 36, No. 22, that the petroleum industry uses large quantities of wrought 4 to 6 per cent. chromium steels because they surpass ordinary steels in creep strength and in resistance to oxidation and corrosion. Shortly after their introduction the creep strengths were increased by alloying the steels with molybdenum or tungsten. However for complete satisfaction, improvements were still necessary. The addition of columbium to the 4 to 6 per cent. chromium steels, especially those containing tungsten or molybdenum has been effective. Columbium eliminates or reduces air-hardening, and thereby facilitates fabrication. Of special interest is the improvement in fabrication by welding. It promotes stability of toughness without loss of creep strength after all heat treatments. Finally it increases the resistance to oxidation at high temperatures.

R. H. O.

Rubber Paving.—The U. S. Bureau of Foreign and Domestic Commerce reports that in Moscow, Russia, there was a test made on a pavement of black and brown rubber. After nine months of severe traffic conditions, including trucks, wagons, and tractors the experiment was declared successful. Advantages claimed are noiselessness, neither snow or ice remains on it, and it is easy to wash. Negotiations are under way by the Moscow City Council for the laying of rubber pavements in one of the large sections of the city.

R. H. O.

A Wide Range Vacuum-tube Resistance Bridge.—I. I. DAVIES. (*Instruments*, Vol. 10, No. 10.) In order to measure conveniently and accurately the electrical resistance of chemically seasoned wood the Forest Products Laboratory designed and developed a portable instrument. It comprises a Wheatstone bridge circuit of the slide wire variety combined with a vacuum tube system for detection of bridge balance. The circuit also includes an a.-c. power supply system. The instrument possesses sufficient sensitivity to make possible resistance measurements over a range extending from less than 100 ohms to more than 200,000 megohms. Unlike most bridge balance indicating systems, this one automatically increases its sensitivity as the balance or null point is approached. Moreover when conditions of extreme unbalance exist, only a predetermined maximum deflection of the milliammeter can take place. The indicator can with slight modifications be used as a vacuum tube voltmeter, capable of measuring an unusually wide range of voltages without drawing current from the voltage source. The instrument is not in commercial production. It was developed in connection with researches on the chemical seasoning of wood and has proved successful in measuring the electrical resistance of wood and other hygroscopic materials with a degree of rapidity and accuracy not common to most moisture meters. The instrument no doubt can also be used successfully to measure leakage resistance in cables and other electrical equipment. A patent covering the complete instrument and its use as a resistance bridge and moisture meter has been applied for and is now pending action by the Patent Office. Should the patent be granted it will be dedicated to the free use of the people of the United States since the instrument has been developed in a Federal research laboratory.

R. H. O.

A Cast Overlay of Corrosion Resistant Alloy.—A method has been developed by which an overlay of a corrosion resistant alloy can be centrifugally cast on to a mild steel base states *Chemical and Metallurgical Engineering*, Vol. 44, No. 10. By fusing a crystalline combination of metallic borides with such base metals as nickel, steel and cast iron, it was found that alloys can be produced that possess interesting physical characteristics, as well as resistance to corrosion and abrasion. One of these alloys, consisting of 75 per cent. nickel and 25 per cent. of the metallic boride crystal combination, was found to have the particular properties necessary so that it could be cast on to a steel base and solidify interalloyed with or bonded to the steel with a comparable bond to that produced in the welded-on overlay or hard facing operation.

R. H. O.

Sorbitol from Glucose by Electrolytic Reduction.—R. L. TAYLOR. (*Chemical and Metallurgical Engineering*, Vol. 44, No. 10.) During recent years the Atlas Powder Co. desirous of diversifying its chemical manufacturing interests, undertook to investigate the commercial possibilities of the higher polyhydric alcohols. The result was what is believed to be the first large scale application of electrolytic reduction in the organic field of chemistry, a synthetic process for making sorbitol and mannitol by the reduction of corn sugar. So successful has the pilot plant been operated at Stamford, Connecticut, that construction of a large plant was pushed ahead at Atlas Point, Del. Purified glucose (American corn sugar) is emptied into a mechanically agitated dissolving tank of distilled water to give a concentrated water solution. Here it is rendered alkaline by addition of sodium hydroxide and sodium sulphate. The solution is pumped to one of twelve electrolytic cells where the water is decomposed to liberate at the cathode nascent hydrogen which reduces the glucose to sorbitol and mannitol, and at the anode nascent oxygen which forms lead peroxide. This latter compound is recovered as a by-product of the process. The product is then given further treatment before drumming for shipment. The characteristics of hexahydric alcohols as chemical raw materials differ only in degree from those of ethylene glycol, glycerine, and other lower members of the polyhydric series. Because of these properties, sorbitol use may be expected to develop as a conditioning agent for textiles, paper, regenerated cellulose sheets, leather, and tobacco. There are many other possibilities also. The present uses of mannitol are in the medicinal and pharmaceutical fields and in the making of fancy papers and resins. Any very extensive commercial use of higher polyhydric alcohols has in the past been limited by both price and supply. However, with a new and steady source of supply now made available, the way is cleared for an extension of known applications as well as research in entirely new fields.

R. H. O.